# Maqam Harmony: Compositional Techniques and Tuning Methods for Achieving Polyphony and Homophony for All Maqamat

Rami Alsabti[1]

**Abstract**

The problem of harmonizing maqamat is based on the difficulty of handling the neutral intervals in some of them. Arab musicians and audiences have never accepted neutral intervals as chords due to their perceived low concordance. By avoiding vertical neutral intervals, composers and arrangers are left with little harmonic options. In this work, I will identify nine maqam pitch properties and nine properties of harmony, analyze how they can be preserved or compromised during harmonization approaches, and offer three solutions with musical examples for maqam harmonization and vertical based composition. First, I offer a compositional technique that allows for polyphonic writing for all maqamat. Second, after careful examining of the literature on perception of mistuning and categorical perception, I then lay out an evidence-based tuning method that preserves maqam's pitch properties, gives access to concordant thirds, and thus allows for both polyphony and homophony for all maqamat. This tuning method, which I call perceptual tempering, is used to generate tunings for maqam rast and 11 other maqamat with neutral intervals, giving them new harmonic intonational profiles. Lastly, I also offer a timbre adjustment method for additive synthesizers that allows them to play more concordant neutral chords. This research aims to establish a theoretical foundation for bridging maqam music with polyphony and homophony with the goal of reaching a new age of maqam harmony for Arabic music.

[1] Independent music researcher, singer, and composer; holds a Bachelor of Arts degree in psychology from York university, Toronto Canada.

# الهارمونيا المقامية: أساليب تأليف وطرائق دَوْزَنَة لتحقيق البوليفونيا والهوموفونيا لجميع المقامات

رامي السبتي[1]

**ملخص البحث**

يتناول البحث مشكلة هَرمَنة (وضع الهارمونيات) المقامات العربية والتي أساسها صعوبة التعامل مع الأبعاد الوسيطة (ما بين الكبيرة والصغيرة) الرأسية. لم يقبل الموسيقيون والجمهور العربي الأبعاد الوسيطة التي تُستخدم بشكل رأسي بسبب إدراكهم بقلة التوافق بينها. بسبب اضطرار المألفين والملحنين والموزّعين إلا تجنب هذه الأبعاد الرأسية في المقامات التي تحتوي عليها، يكون أمامهم خيارات هارمونية قليلة. في هذا البحث، سأحدد تسع خصائص تتعلق بالحِدّة للموسيقى المقامية وتسع خصائص للهارمونيا، سأحلل كيف من الممكن للطرائق المختلفة للهرمنة أن تأدي إلا الحفاض أو الإخلال بهذه الخصائص، وسأقدم ثلاثة حلول للهرمنة والتأليف العمودي مع أمثلة موسيقية. أولًا، سأقدم أسلوب تأليف موسيقي يسمح للكتابة البوليفونية لجميع المقامات. ثانيًا، بعد فحص دقيق لبحوثات تتناول قدرة المستمع على إدراك سوء الدَوزَنة الموسيقية وقدرة تصنيف الابعاد الموسيقية، أضع طريقة دَوزَنة مبنية على الأدلة تحافظ على خصائص الحِدّة المقامية، تتيح إلى ثالثات متوافقة، وبالتالي تسمح للبوليفونيا والهوموفونيا لجميع المقامات. أستخدم هذه الطريقة، التي أُسميها التعديل الإدراكي، لإنتاج بيانات دَوزَنة لمقام راست و11 من المقامات الأخرى التي فيها

[1] باحث موسيقي مستقل، مغني، ومألف موسيقي. حاصل على بكالوريوس علم النفس من جامعة يورك، تورونتو كندا.

الأبعاد الوسيطة مما يمنحها طوابع تنغيمية هارمونيّة جديدة. ثالثًا، أقدم أيضًا طريقة لتعديل الجَرْس (لون الصوت) للمُركِّبات الموسيقية الإلكترونية ذات التركيب الجمعي تُمكِّنها من إنتاج أبعاد وسيطة عمودية ذات توافق اعلى. يطمح هذا البحث ان يأسس البنية التحتية النظرية لدمج الموسيقى المقامية مع البوليفونيا والهوموفونيا بهدف الوصول الى عصر جديد من الهارمونيا المقامية للموسيقى العربية.

**Glossary of General Terms**:

***Jins* –** A selection of three to five scale tones that together yield a scale fragment or mini scale. They can be trichords (3 notes), tetrachords (4 notes), or pentachords (5 notes).

***Ajnas* –** Plural of jins.

***Maqam* –** A scale, usually heptatonic, made up of a combination of ajnas.

***Maqamat* –** Plural of maqam.

***Ghammaz* –** The ghammaz is somewhat equivalent to the dominant in western music. In maqam music, it is the scale degree that can become the tonic of a jins or maqam that are not part of the original scale.

***Neutral* –** Designates an interval as one that is theoretically halfway between major and minor. When used in its short form, ‘N’, before an interval, it means that the perfect or major versions of that interval are theoretically decreased by 50 cents. So a N5 is 650 cents and a N3 is 350 cents.

***Sayr* –** The monophonic melodic development of the musical work in maqam music.

## 1. Introduction

The problem of harmonizing maqam music is not a problem to those critical of the venture itself. They view maqam music as complete and believe that it should not aspire to adopt western identities that would compromise its own in the process (Ben Yousef, 2016). Critics rightly point out that adding a vertical dimension to an otherwise wholly horizontal music can distract from the melodic development and thereby rob the music of that core element. Others, however, see that appropriate harmonization can preserve maqam's identity if it adds colors that strengthen the expressiveness of the music (Al-Rubay'i, 2015). There have been many attempts to blend the two repertoires, Arab and western, by composers and arrangers in the 20th century that have received wide acceptability from the Arab audience (Al-Rubay'i, 2013).

Recently, there have been some projects attempting to discover and highlight how elements from both maqam and western repertoire can be blended through harmonization and arrangement (Battah, 2018; Between Two Cultures, 2021), and through the genre of jazz (Medinea, 2019; Molinaro, 2023). Salvucci (2016) argued that Turkish makam music can follow the same development that gave rise to polyphony in medieval and renaissance European music through contrapuntal writing. Martin[1] (2016) undertook the only serious study of maqam homophony that I am aware of. There have also been attempts to combine maqam music with spectral composition techniques (Chahin, 2017). There has yet to be a theoretical work that acts as the foundation of maqam harmonization for the future. There are plans, however, to write books based on

[1] Listening to the many maqam piano harmonizations in his website in 2018 was one of the things that inspired me to go on this journey.

spectral approaches to harmonization (Abou Diab, 2023), and polyphonic contrapuntal writing methods (Abu Dhabi Festival, 2022).

I have focused on the problem of attaining homophonic textures for all maqamat since 2018. Following the completion of my tuning methods approaches and analysis to the homophony problem, and feeling satisfied with my solution, I decided to see if I can arrive at a compositional technique specific for polyphonic contrapuntal writing. I was partly inspired by how Salvucci (2016) developed this exact technique for Turkish makam music and by the announcement of a polyphonic technique by Qoutayba Neaimi for Arabic music as well (Abu Dhabi Blog, 2021). Thus, I set out to see if I can develop a similar technique to theirs. In this work, I will lay out a polyphonic compositional technique that can be used for all maqamat, my tuning method solution that can achieve both homophony and polyphony for all maqamat, and a timbre adjustment method for additive synthesizers that allows vertical neutral intervals to be more concordant.

## 2. Maqam’s Pitch Properties

We must first identify maqam’s pitch related properties which can either be preserved or compromised throughout harmonization. Maqam music, like the music of many cultures, divides the unidimensional psychophysical continuum of pitch into discrete piece-wise steps to be used in musical scales (Deutsch, 1998, p. 218; Dowling & Harwood, 1986, p. 123; Hallam et al., 2016, pp. 73–74). From the pitch continuum, some pitches are combined to form melodic intervals, which are combined to form ajnas, which are ultimately combined to form maqamat. The traditional musical texture in maqam music is monophony. This means that Maqam’s interval properties +

maqam's ajnas properties + maqam's scale properties + maqam's monophonic properties = all of maqam's pitch properties, and therefore = maqam's pitch identity. In the process of applying polyphonic and homophonic textures to n-maqamat[1], some of these properties will be compromised. One of the goals of this research is to discover how specific compositional techniques and tuning methods that allow for polyphonic and homophonic textures for n-maqamat can cause compromises, or lack thereof, in maqam's pitch identity.

According to Marcus (1989), maqamat first began to be described by melodic intervals in the late 19th and early 20th centuries (pp. 257–258). This change was facilitated by the introduction of the 24 Divisions Per Octave (EDO) system in the theoretical work of Mikhail Mishaqa (Touma, 2003, p. 19). This allowed later theorists to conceive of maqamat as scales in 24 $_{\text{EDO}}$, necessitating a discussion of the melodic intervals between scale tones (Marcus, 1989, pp. 257–258). Because it remains a staple in Arabic music education to this day, I will conceptualize the intervals, ajnas, and maqamat in 24 $_{\text{EDO}}$ as a departure point for my analysis.

### *2.1 Interval Properties*

A musical interval is the difference in pitch between two tones and is measured in cents, the logarithmic unit of measurement for musical intervals. A melodic interval is the difference in cents between two successive tones. When the successive tones are

[1] An n-maqam possesses scale tones that form neutral intervals (ex: neutral second, neutral third, neutral fifth, etc.) with other scale tones.

adjacent scale tones the interval is referred to as a scale step. If we want to refer to a hypothetical scale step outside the context of a particular scale, we simply call it a step.

**2.1.1 The JND**. A universal feature common to scales across cultures is the discriminability of tones (Dowling & Harwood, 1986, pp. 92-93). The ability to discriminate between two successive tones diminishes the more the difference in pitch between them approaches zero. Before that occurs, the difference will first reach a particular threshold where discriminability becomes difficult, and the tones are perceived to be the same. This threshold is called the Just Noticeable Difference (JND)[1] of melodic or successive tones. There have been many different accounts of what the JND is in values of cents, with some reports of it being $10_c$ (Hill & Summers, 2007), $20_c$ (McDermott et al., 2010), and $33_c$ for musicians and non-musicians in a melodic discrimination task (Parncutt & Cohen, 1995). Hunt (2008) has interpreted the JND findings in the literature in cents and reported a value of $3.5_c$ as the lowest discriminable threshold and a value of $6_c$ as the average JND. I will use $6_c$ as the value for JND in my analysis.

**2.1.2 Smallest Theoretical Step is $50_c$**. Marcus (1989) discusses the disagreement between theorists on whether there are four, five, or six steps that can be combined to create Ajnas (p. 258). The six steps in question, from $24_{EDO}$, are the $50_c$[2], $100_c$, $150_c$, $200_c$, $250_c$, and $300_c$ steps; these represent the quartertone, semitone, neutral second, whole tone, five quarter tone, and augmented second, respectively. Mcbride &

[1] The JND is used to measure other sensory modalities, but in this paper, I will use JND to specifically refer to the discriminability threshold of successive or melodic tones.
[2] The letter ‘c’ after a numeral denotes a value in Cents.

Tlusty (2019) analyzed a large cross-cultural database of scales and found that "most people cannot tolerate intervals smaller than about $50_c$". Maqam music is one such culture where steps smaller than the quartertone do not exist theoretically.

**2.1.3 Interval Identity**. Melodic intervals have been extensively examined through interval identification and interval discrimination tasks in categorical perception studies (Deutsch, 1998, pp. 219-235). One robust finding is that despite significant differences in the sizes of melodic intervals, they can nonetheless retain their essential melodic information (Deutsch, 1998, p. 231). This is exemplified by listeners identifying or discriminating an interval into the same category despite different tunings of the interval. Therefore, interval identity is preserved when the interval is tuned such that it retains its inherent melodic information[1]. There are Arab musicians who believe that there is significant intonational mobility and variation in the sizes of the melodic steps of maqam music, and yet there are some who believe that there are no notes beyond the 24 $_{EDO}$ ones (Marcus, 1989, p. 203). This means that, for now, we can proceed with 24 $_{EDO}$ as an acceptable conceptualizer of the intonation of the melodic steps used in maqam music[2].

***2.2 Ajnas Properties: Jins Identity.***

Each jins acquires its unique identity from its intervallic makeup. For example, jins rast on C would be C-D-E𝄳-F; its steps are one M2[3] (from C to D) and two N2s[4]

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[1] I will discuss this in detail in sections 6.4 and 7.1.
[2] 24 $_{EDO}$ is used in the Arabic Pop music industry which has a massive and wide audience.
[3] Major second.
[4] Neutral seconds.

(from D to E𝄳 and from E𝄳 to F). Furthermore, the way in which the steps are ordered also matters. The steps of jins rast must be ordered in the following manner: M2 between degrees 1-2, a N2 between degrees 2-3, and a N2 between degrees 3-4. This is commonly written as 1-3/4-3/4 in music theory textbooks[1]. If we were to change the steps such that the intervallic makeup is 3/4-1-1, for example, then we would end up with jins bayati instead. A jins is a higher order category made up of smaller categories, the melodic steps. Jins identity is therefore preserved when the identity and ordinal position of all its steps are preserved.

***2.3 Scale Properties***

**2.3.1 Octave Equivalence**. Another universal feature of scales that is common across cultures is octave equivalence whereby tones that have an octave relationship between them are treated the same (Dowling & Harwood, 1986, p. 93). Marcus (1989) states that as far back as the early 19th century, Arab musicians had terminology for indicating that a note is an octave higher or lower (pp. 78-79), and that Arab theorists in the early 20th century treated a maqam an octave higher as simply a derivative of the same maqam (p. 77). There are maqamat where octave equivalence is purposefully avoided for some scale degrees, like the tonic, but the perception that two tones an octave apart are related is ubiquitous for maqam music listeners and the music itself.

**2.3.2 Moderate Number of Scale Tones.** Another universal property of musical scales is that an octave should be filled up with a moderate number of scale tones (Dowling & Harwood, 1986, p. 93; Hallam et al., 2016, p. 74). This is due to the

[1] These are steps in 24 $_{EDO}$ where 1 = a M2 (whole tone, $200_c$) and ¾ = three quarters of a whole tone (three quarter tone, $150_c$).

principle of cognitive economy whereby organisms use categorization to reduce informational overload and free up cognitive resources that are needed for survival (Deutsch, 1998, p. 218). This explains why most cultures use scales with five to seven tones. Maqam music is one such culture as most maqamat possess seven tones with few exceptions.

### *2.4 Monophonic Properties*

The previous properties of intervals, ajnas, and scales were all atemporal. They do not need the music to proceed temporally to be realized. They can be preserved simply through theoretical scale construction. The following properties, however, relate to the temporal nature of monophonic maqam music. We can only judge whether they are preserved or compromised when the music proceeds in time.

**2.4.1 Stepwise Melodic Development**. In Bregman's (1990) theory of auditory scene analysis, a large melodic interval break a melody into two separate streams; this process is called streaming or segregation. The second tone, being a distance of a fourth, fifth, or a larger interval away from the first tone, is perceived as belonging to a different source due to the gap in between them (Parncutt, 2018). The perception that the tones have two different sources interferes with melodic coherence (the perception that pitches belong to one stream or voice) because there is no close pitch proximity between the tones (Huron, 2001). Auditory scene analysis can explain some important things here. First, stepwise melodic development, as opposed to other melodic developments, is selected for because it promotes melodic coherence. Maqam music does not involve frequent skips and leaps because there was a cultural bias to preserve melodic coherence. This is also true for western contrapuntal music. Furthermore, aside from maintaining the same tone in a voice, the next best stream cohesion results from movement by roughly two semitones or less (Huron, 2001). This may explain why maqam music is overwhelmingly dominated by stepwise motion, a bias to preserve stream coherence, which then preserves melodic coherence. Second, since a melody is perceived to belong to the same stream (source) if its tones fall within a fourth or a fifth, this then explains why ajnas are never larger than a P5[1], due to the same cultural bias[2]. Ajnas may simply be the smallest possible scale fragments that promote melodic coherence. Maqam music very often utilizes stepwise melodic development on one jins before moving to another jins to do the same, without necessarily playing tones from both at the same time. This shows that modulation in maqam music may also be biased towards achieving stream coherence.

**2.4.2 Sayr Voice Intonational Profile Consistency**. The sayr in Maqam music is the monophonic melodic development of the musical work. The sayr voice is the voice that carries the sayr, the monophonic melody. An oud solo has one sayr voice and no other accompanying voices. In an ensemble, when a singer sings the melody, they are the sayr voice, and the other voices are copies of it providing monophonic and heterophonic accompaniment; when a solo instrumental part comes in, it assumes the

[1] Perfect fifth.

[2] Biases from the human auditory system interact with cultural biases and choices to explain music-related cultural customs and traditions. The choice is ultimately cultural. Biases from our auditory system simply provide one angle of explanation for why certain cultural choices may have been made, as opposed to others.

role of the sayr voice at the forefront of perception. Monophony therefore has one sayr voice that can be arranged for many instruments.

There is significant intonational variation in Maqam music across the Arab region (Abu Shumays, 2009; Marcus, 1993). Maqam Rast can have a specific intonational profile in Egypt, a different one in Syria, and another different one in Iraq, for example. These can be thought of as different dialects of the same melodic language (melodic material), which in this case is maqam rast. However, a musical work that begins in one intonational profile does not typically transition to another one at a later moment in the work; that would create intonational profile inconsistency. A song that begins with an Egyptian intonation of maqam rast, for example, does not use a Syrian or Turkish intonation of the same maqam at later points.

Mistuning is more disruptive for prominent pitches, such as those in a melody, compared to those in its accompaniment (Rasch, 1985). Listeners can also hear frequency differences in the context of a mistuned melody that they are unable to hear in an isolated context (Warrier & Zatorre, 2002). Since the sayr voice carrying the melody is always at the forefront of perception, it is more susceptible to perceptions of mistuning. We can sum up these findings by stating that each intonational profile may be acceptable in and of itself, with a large variety of different regional intonational profiles all deemed acceptable for most audiences, but that a perception of mistuning will occur if they were to be alternated with each other in a short amount of time. There is evidence that changing the expected melody produces increased activity in brain regions associated with working memory (Zhang et al., 2022); this may also partly explain the bias for intonational profile consistency in the sayr voice.

**2.4.3 Tonic Stability**. Regardless of the different intonational profiles that exist for the same Maqam in different regions, the tonic pitch does not deviate much throughout a musical work. This is because the tonic is the tonal center of the entire sayr, and thus significant deviations in its pitch can severely impact the tonality as a whole. Even though there is some consensus that certain degrees of a Maqam can have more intonational mobility than others (Marcus, 1993), there is always unanimous consensus that the tonic pitch should be as consistent as possible.

**2.4.4 Acceptable Usage of Non-Scale Tones**. In Maqam music, the sayr proceeds by tonicizing the tonic degree of a maqam, then highlighting the lower and upper ajnas of that maqam, and then optionally introducing more melodic development through modulations to other ajnas and other maqamat. There are customs for how modulations work[1] and how non-scale tones are introduced and employed in Maqam music (Farraj & Abu Shumays, 2019, pp. 297-333; Marcus, 1992). Non-scale tones that are members of ajnas that are not part of the currently tonicized maqam can nonetheless be a part of the potential sayr of the maqam. Therefore, non-scale tones will be deemed as sayr tones if there is a realistic potential sayr that can access them, and as non-sayr tones if there is not. Melodically, this property is preserved when non-scales tones are utilized as sayr tones according to the modulation customs of maqam music.

[1] Such as the tonicization of other ajnas not part of the original maqam scale on the ghammaz degree(s) of the maqam, which are the degrees traditionally decided upon as acceptable hosts of tonics of other ajnas.

## 3. Harmonizing the Fundamental Scale

Maqam rast is known as the fundamental scale in Arabic music (Marcus, 1993). Harmonizing maqam rast will give us a good indication of whether a compositional technique or tuning method is applicable to other n-maqamat. I will analyze and harmonize maqam rast C which consists of the notes C, D, E𝄳, F, G, A, and B𝄳. Maqam rast in 24 $_{EDO}$ cent values is: $0_c$–$200_c$–$350_c$–$500_c$–$700_c$–$900_c$–$1050_c$. Throughout the attempts of harmonization, we will encounter properties of harmony that can be preserved or compromised. We will also encounter compromises to maqam's pitch properties as well.

### *3.1 Field Analysis*

We must analyze the notes of maqam rast before we attempt harmonization. A good starting point is to conceive of 24 $_{EDO}$ as being made up of two fields, as Alois Haba did (Battan, 1980). The notes C, D, F, G, and A all belong to one field because they are linked by a chain of a nearly perfect fifth[1]. Likewise, the notes E𝄳 and B𝄳 belong to the other field, also linked by a chain of a nearly perfect fifth[2]. In a scale, the field that has the majority share of representation via notes will be signified as the primary field, and the field that has the minority share as the secondary field[3]. Thus, the

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[1] The nearly perfect fifth in 12 $_{EDO}$ is $700_c$. When this interval is stacked on top of itself iteratively, while subtracting the octave ($1200_c$), all 12 tones of 12 $_{EDO}$ can be attained. Some oud, qanun, and violin players still tune their instruments this way, resulting in what is called Pythagorean tuning. In actuality, this tuning method has Mesopotamian origins (West, 1994; De Rose, 2021).

[2] The other 12 tones of 24 $_{EDO}$ have the same relationship amongst themselves. 24 $_{EDO}$ is effectively two scales of 12 $_{EDO}$ separated by $50_c$.

[3] This conceptualization does not disdain the field containing the pitches we mark with half-flat and half-sharp symbols as ontologically secondary or inferior. This way, if we built maqam rast on the tonic of E𝄳, for example, then E𝄳, F𝄲, A𝄳, B𝄳, and C𝄲 would be the primary field tones, while G and D would be the secondary field tones.

notes C, D, F, G, and A belong to the primary field, and the notes E𝄳 and B𝄳 belong to the secondary field.

### *3.2 Psychoacoustic Roughness*

Mixing tones from the primary and secondary fields vertically will result in neutral vertical intervals, like the $350_c$ N3[1] between C and E𝄳 and the $650_c$ N5[2] between A and E𝄳. Some neutral intervals, like the N3, will have rapid amplitude modulation amongst some of their partials that creates a sensation of beating or roughness. Psychoacoustic roughness is only one part of musical consonance and dissonance (Di Stefano et al., 2022; Parncutt & Hair, 2011), and there are cultures that use rough vertical intervals in their repertoire (Ambrazevičius, 2016), but it may nonetheless partly explain why the vertical form of maqam's neutral intervals was never adopted by Arab musicians and their audience[3].

Neutral intervals can, however, sound more acceptable vertically when the notes are arranged exactly as segments from the harmonic series. The earliest jins rast in the harmonic series, for example, is 9:10:11:12. Supposing our tonic is C, the jins would thus be C-(10/9)-D-(11/10)- E𝄳-(12/11)-F. When this jins is voiced as a tetrad, for example, as C3[4]-D4-E𝄳4-F4, it will sound like a harmonic series segment with the

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[1] Neutral third.

[2] Neutral fifth.

[3] The Arab audience has never accepted synchronous simultaneous vertical neutral intervals. They refer to them as "nashaz", meaning cacophony, a discordant mixture of sounds. Non-chord tone neutral vertical relations, akin to false relations in European renaissance music, are common, however, and well accepted.

[4] A number after a note's musical symbol denotes the octave number of that note.

periodicity and phase-locking effect associated with just intonation[1] (JI) chords. If voiced in timbres that facilitate the phase-locking, it will sound more pleasant than a regular neutral triad, like C-E𝄳-G. There is evidence that phase-locking is associated with higher ratings of consonance (Di Stefano et al., 2022), but this spectral approach to maqam harmonization requires adding seconds, fourths, and other notes to the root of a chord that ultimately make it more complex and can lead to interference with basic melodic perception. This complexity makes the chord a completely different unit of perception than the established vertical units in western music that rely on thirds and fifths as units of stable consonance, and other intervals as unstable but colorful additions; a harmonization approach that may not distract from the melodic development if used appropriately. Just as thirds were once deemed unstable in early European polyphony (Schulter, 1997), and so too were sevenths before they were adopted into the tonic chords in jazz music, the vertical neutral intervals need time for the Arab audience to accept; they may also never accept them. We cannot adopt complex units of perception before we allow the culture to be desensitized to simple units first; the contrast in the transition is too steep. My goal, instead, is to find a solution that has immediate acceptability by the Arab audience.

The first issue facing any harmonization attempt of an n-maqam is the psychoacoustic roughness of the vertical N3s; without stable 3rds there will not be stable 6ths, and our harmonization options thus become very limited. Although some have embraced neutral triads (Didi, 2020), they must nonetheless be deemed a problem

[1] "Just intonation" commonly refers to 5-limit just intonation where all the intervals are ratios derived from the number 3 and its powers (like the P5, 3/2) and the number 5 and its powers (like the M3, 5/4).

because the Arab audience will likely not accept them anytime soon. A solution must therefore be devised. Thus, *concordance* of vertical intervals is the first property of harmony that can be compromised.

***3.3 Harmonic Material Analysis***

The consonant harmonic material in maqam rast C is five P5s[1] (and thus five P4s[2]) and three 12 $_{EDO}$ tuned thirds (and their equivalent sixths). This may seem like enough material to work with, but since notes from the primary field cannot be harmonized with notes from the secondary field, and vice versa, the E𝄳 and B𝄳 only have each other as harmonizable options. This reveals another property of harmony: *harmonic availability*. This property concerns the availability of harmonizable options that a scale tone has with other scale tones.

This is extremely limiting for part writing, as the nearest harmonizable note for both the E𝄳 and B𝄳 is either a fourth or a fifth away. It results in frequent leaping, a lack of smooth stepwise contrary motion in voice leading and can therefore compromise the maqam property of stepwise melodic development. Harmonization attempts of maqam rast have historically involved parallel motion of the P5s of the scale, but not every scale degree possesses a P5 for that matter. There are two N5 intervals, A-E𝄳, and B𝄳-F, and these must be avoided as well. Adding another voice and assigning it to maqam rast C will not provide solutions to these issues, as it will have the exact same pitch material. Therefore, we need non-scale tones, pitches from outside of the scale.

[1] Perfect fifths.
[2] Perfect fourths.

## 4. Polyphony

### *4.1 Gathering New Harmonic Material*

Salvucci (2016) discussed how different Turkish makams could be paired together in polyphonic writing based on features they have in common (pp. 149-151). In our case, the best candidates to provide non-scale tones are maqamat that share many pitches in common with maqam rast C. The best of these is maqam rast G, as it shares its first jins (jins rast on G) with the second jins of maqam rast C (also jins rast on G). Maqam rast G provides two new pitches from its second jins (rast on D), E and F‡; these form P5s with A and B𝄳, respectively, and therefore allow P5s to be accessible for every scale degree of maqam rast C. The F‡ provides a new harmonizable option for the secondary field, forming a P5 and P4 with B𝄳 and a M2 and m7[1] with E𝄳.

If we assign all nine notes to one voice and do the same for another voice, then each voice will be able to play this combined scale of nine pitches. The combined scale will be made up of all seven pitches of maqam rast C with the two non-scale tones, the E and F‡, from maqam rast G. However, the two voices will need to abide by the property of acceptable usage of non-scale tones. For example, the E and F‡, from maqam rast G, belong to jins rast on D. It will be difficult to employ these two tones as acceptable sayr tones because jins rast on D is not a traditionally acceptable jins to modulate to directly from maqam rast C (Marcus, 1992). Therefore, this approach can compromise this maqam property. Restricting the sayr of each voice in advance is therefore advisable. For example, if we employ two voices and assign one of them

[1] Minor seventh.

strictly to maqam rast C, and the other strictly to maqam rast G, then they can both play their own independent sayr with acceptable sayr tones but meet vertically to create a polyphonic texture. This is what Salvucci (2016) theorized and why this compositional technique is best used for polyphonic writing where each voice is restricted to its own independent maqam and tonic. We can therefore call the voice that plays maqam rast C: sayr voice rast C, and the voice that plays maqam rast G: sayr voice rast G.

### *4.2 Contrapuntal Writing*

Sayr voice rast C and sayr voice rast G can be combined to create all the types of species counterpoint. Figure 1 is an example of note-against-note counterpoint for two sayr voices rast C and one sayr voice rast G; all three voices are written for piano. Voice leading considerations here include the need to adhere to rules of counterpoint as much

**Figure 1**

*First Species Counterpoint for Two Sayr Voices Rast C and One Sayr Voice Rast G*[1].


[1] (Maqam Harmony, 2024b) (see Supplementary Music Examples); https://youtu.be/IehltdUC43c

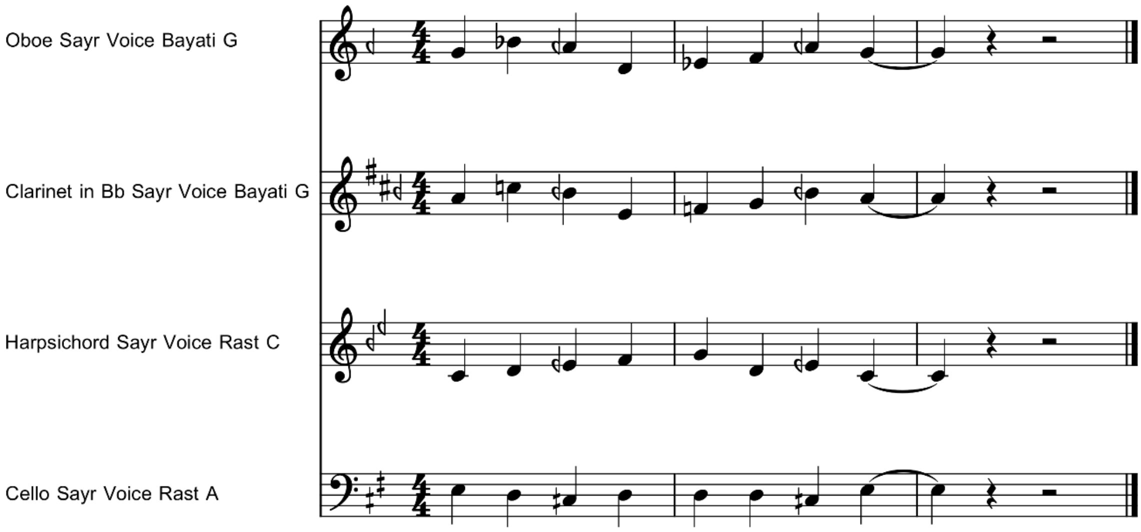
as possible, making sure to traverse from highly blending perfect intervals to non-blending imperfect intervals and back[1], accounting for metric stress, and making sure the first and last sonorities (chords) use perfect intervals. Nonetheless, however, the harmonic material is still restrictive. E𝄳 is mostly used with B𝄳 because F♯ forms a rather dissonant 7th with it. Haba recommended that traversing between sonorities in one field to sonorities in another should be done by stepwise contrary motion (Battan, 1980, p. 79), but what is also important is to consider the inherent concordance of the intervals, the metric position of both sonorities, and the timbral combination of the voices. It's not that the E𝄳 and F♯ form an inherently discordant and unusable interval, but rather that the homogeneous piano timbre creates a perception of timbral uniformity that is susceptible to breaking when two very distant chords (such as a chord from the primary field and a chord from the secondary field) are played consecutively; if the second chord has blending intervals, however, then this non-uniformity can be mitigated[2].

Figure 2 is an example of note-against-note counterpoint for one sayr voice bayati G, one sayr voice rast C, and one sayr voice rast A. The use of different timbres yields a heterogenous timbral texture; each voice now has timbral independence. If we were to only use sayr voice rast C and sayr voice bayati G then the E𝄳 and B𝄳 from maqam rast C will only have the A𝄳 from maqam bayati G as a harmonizable option.

[1] For useful voice leading guidelines based on thirteenth century multi-voice polyphonic combinations and cadences, see Schulter (1997).
[2] It can also be mitigated by avoiding the piano timbre and using timbres that have more vibrato instead.

**Figure 2**

*Note Against Note Counterpoint for One Sayr Voice Bayati G, One Sayr Voice Rast C, and One Sayr Voice Rast A*[1].




*Note*. The Bb clarinet sounds one whole tone lower than notated. Both the oboe and clarinet are playing bayati G in unison. Therefore, there is only one sayr voice bayati G.

This is why adding another sayr voice may be useful. Sayr voice rast A is chosen because maqam rast A has the notes C𝄲 (which forms a triad with the A𝄳 from maqam bayati G and the E𝄳 from maqam rast C) and G𝄲 (which forms a triad with the E𝄳 and B𝄳 from maqam rast C). This gives us more notes for the secondary field and thus more harmonizable options for said notes.

Maqamat can be selected in this way to yield the tones that are desired for specific fields or chords. However, the more we use independent tonics, the more their tonalities will compete. Since maqam music is traditionally monophonic, its tonality is

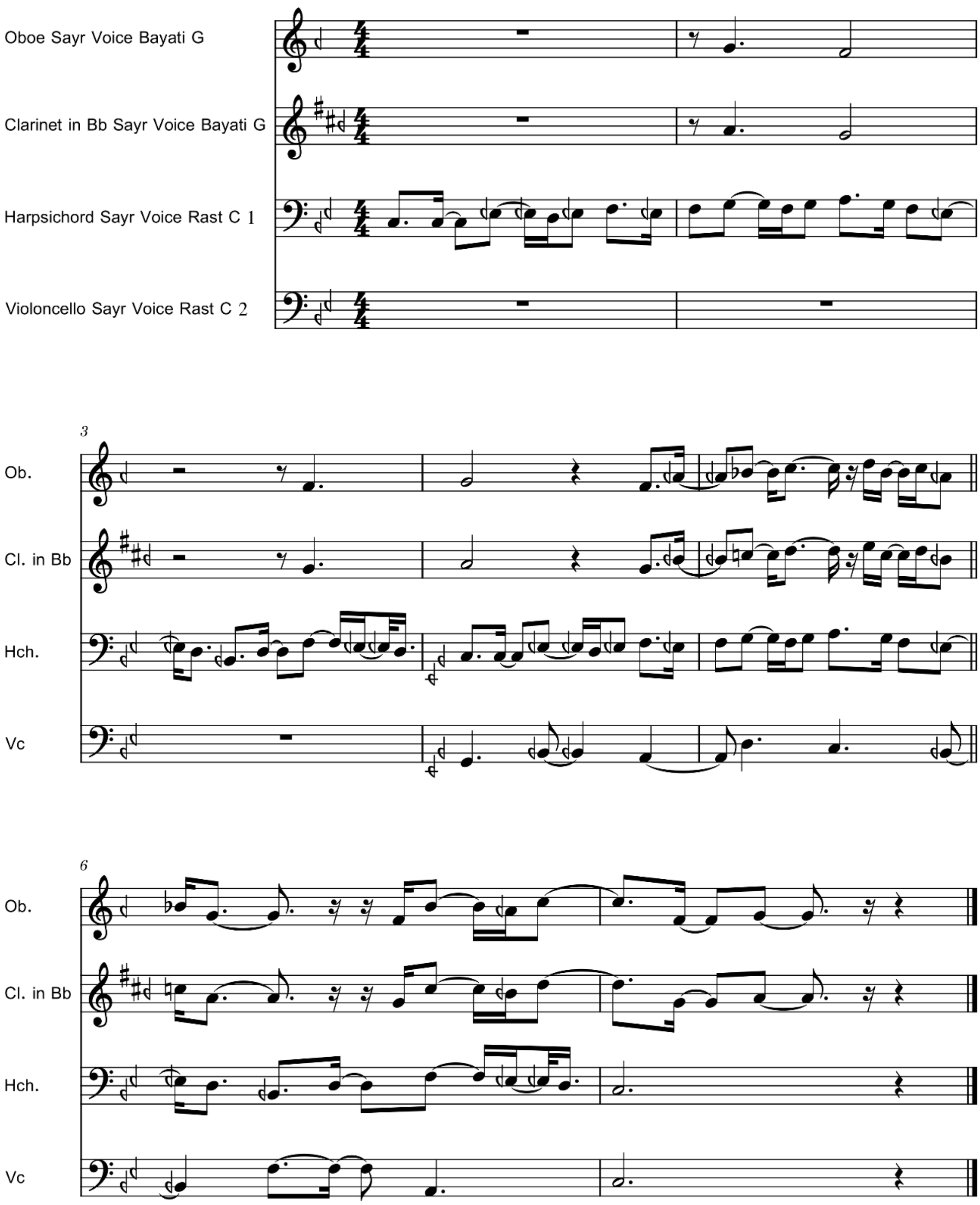
[1] (Maqam Harmony, 2024c) (see Supplementary Music Examples); https://youtu.be/hMWvGUq5HOo

therefore necessarily imposed in a monophonic way, via one melody that takes the tonal centre. When a sayr voice's tonality is being competed with via the inclusion of other melodies from other ajnas or maqamat that hinder the tonicization or tonality of that sayr voice, this monophonic tonality is compromised. *Monophonic tonality* is thus another property of maqam that can only be revealed during harmonization. The example from figure 2 works because it is homorhythmic. The tonalities of sayr voice rast C and sayr voice rast A have timbral independence, but are tonally subservient to the tonality of sayr voice bayati G. The combined timbre and dynamics from the oboe and clarinet dominate the timbre of the other two sayr voices and create tonal clarity for maqam bayati G. If the three sayr voices were to be employed polyrhythmically, however, then the rhythmic independence will overwhelmingly highlight each maqam's tonal independence, and the result will be a clashing of tonalities, and thus a compromise in the monophonic tonality of each voice.

To preserve the property of monophonic tonality, sayr voices that have different tonics need temporal independence when imposing their tonalities, unhindered by other sayr voices. Imitative counterpoint compositional techniques, like the round, canon, and fugue, are very useful for facilitating this. Figure 3 is an example of polyrhythmic counterpoint for two sayr voices rast C and one sayr voice bayati G. The sayr voices use melodic development where each tonic begins and ends independently of the other. Temporal independence is also required for cadences so that tonicization of each voice's tonality can be unhindered by other voices. These considerations will preserve monophonic tonality for each sayr voice.

**Figure 3**

*Poly-Sayr Example for One Sayr Voice Bayati G and Two Sayr Voices Rast C*[1]*.*




[1] (Maqam Harmony, 2024a) (see Supplementary Music Examples) https://youtu.be/eGgUnspuPd4

### *4.3 Poly-Maqam*

In the previous polyphonic writing examples, the harmonic material gathered to harmonize the fundamental scale came in the form of non-scale tones that belong to other maqamat. When two or more sayr voices each have their own assigned independent tonic the result is a polyphonic compositional technique I call *poly-maqam*. This technique requires the compositional management and balance of the elements that make a voice independent: jins, maqam, tonic, sayr, rhythm, timbre, and time so that the property of monophonic tonality is preserved, just as my previous examples highlighted. The opposite of poly-maqam is *homo-maqam*. We can have polyphony in homo-maqam as well; the voices can each have an independent sayr, rhythm, timbre, or time, but they must share the same tonic. This is the core difference between the compositional techniques of poly-maqam and homo-maqam.

## 5. Homophony

Homophony is exemplified by the use of one dominant melody with an accompaniment. When the accompaniment is homorhythmic to the melody, the result is homorhythmic homophony[1], a common example of which is a typical arrangement for big band where the accompanying voices harmonize the melody homorhythmically. When the accompaniment is polyrhythmic to the melody, the result is polyrhythmic homophony[2], a common example of which is a typical pop song with chords moving polyrhythmically to the singer's melody.

[1] Also called chordal style/arrangement.
[2] Also called melody-dominated homophony and monody.

### *5.1 Homo-Maqam*

Because the voices in Figures 1 and 2 of the poly-maqam examples are all homorhythmic, some listeners may perceive a homorhythmic homophonic texture. When poly-maqam is used in this way, it may indeed yield an acceptable homorhythmic homophonic texture, but it has its limitations. Since poly-maqam uses two or more independent maqamat/tonics, the voice that needs to be highlighted as the main sayr voice must constantly have timbral dominance, otherwise some of the tones of the other voices may segregate (diverge from the uniform texture) and be perceived as non-scale tones of the main sayr voice. This can either compromise the condition of homophony that only one melody should be at the forefront of perception or potentially other properties of harmony that we will discuss in this section. For polyrhythmic homophony, all the notes needed for the chordal accompaniment could theoretically be retrieved from other maqamat and then assigned to voices with independent tonics/maqamat, but this will either create synchronous or non-chord tone relations between the scale tones of the main sayr voice and the non-scale tones from the accompanying voices and could lead to the same aforementioned compromises. For these reasons, poly-maqam is more suited for achieving polyphonic textures. Let us now explore how homo-maqam can be utilized to achieve homophonic textures.

### *5.2 Triads of the Fundamental Scale*

The basic chord progressions in western music involve the extraction of the triads of a scale and then representing each triad with specific roman numerals. When the roman numeral is written in uppercase the triad is major, and if in lowercase then it is minor. These, however, will not be representative of every degree of the fundamental scale as some of them are secondary field tones. Therefore, I will use western Arabic numerals[1] to signify that a chord is built on a scale degree that is a secondary field tone in the scale.

Roman numerals will be used for triads whose roots are primary field tones of the scale while Western Arabic numerals, like 3 and 7, will be used to signify that a triad's root is a secondary field tone occupying the third and seventh scale degree positions, respectively. An 'n' before a numeral signifies that a chord possesses a neutral third between the root and third; uppercase or lowercase roman numerals in this case do not change the informational content of the chord. C-E𝄳-G is therefore $^{n}$I, G-B𝄳-D is $^{n}$V, and E𝄳-G-B𝄳 is therefore $^{n}$3. A 'd' after a numeral signifies that the triad possesses a N5. $^{n}7^{d}$ is therefore B𝄳-D-F. Lastly, vi$^{d}$ indicates that a primary field tone on the sixth degree is the root, that there is a m3 between the root and third (due to the lowercase vi), and that the fifth is a N5; the chord's notes are therefore A-C-E𝄳. The triads of the fundamental scale are thus: $^{n}$I, ii, $^{n}$3, IV, $^{n}$V, vi$^{d}$, $^{n}7^{d}$.

### *5.3 Tuning Methods for Chord Progressions*

Giedraitis (2019, Chapter 4.7) discusses tuning methods that microtonal music theorists have devised to counteract specific compromises in the properties of harmony that result from chord progressions that use common-tone or oblique motion[2]. Common tone chord progressions are a prominent characteristic of homophony. These methods

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[1] These can be exchanged with eastern Arabic numerals that are more unique and thus cannot be easily conflated with regular numerals. I, however, will use western Arabic numerals in order to promote the ease of use on one keyboard system, and to not obscure matters for the lay audience.
[2] See also (Erlich, 2001).

are specific to the conversion of 12 $_{EDO}$ chord progressions to JI and managing the syntonic comma ($21.5_c$). I will be interpreting these methods in the context of maqam music while retaining as much as possible from their characteristics. I will use the methods, one at a time, to tune the following chord progression from maqam rast C: $^{n}$I–$^{n}$3–IV–$^{n}$7$^{d}$–ii–$^{n}$V–$^{n}$I.

I will use this progression along with a melody I wrote for it to test how each method produces polyrhythmic homophony. Each method will allow us to discover more properties of harmony that can be compromised.

**5.3.1 Wolf Method**. A wolf is any vertical interval that has unpleasant discordance due to beating or roughness. N3s are therefore wolf thirds and N5s are examples of wolf fifths. The wolf method only uses the scale tones of maqam rast C to tune the triads of the progression. The result, as discussed previously, is psychoacoustic roughness from the N3s and N5s. This method therefore compromises the concordance property of harmony. We can break this property down into the subcategories: 8ves, 5ths, and 3rds. Therefore, this method specifically compromises the concordance of 3rds and 5ths. These intervals, along with their inversions, are generally classified as consonant. If we cannot achieve concordance in our consonant intervals then we will not be able to have consonant harmonies at all.

***5.3.1.1 The $^{n}$I Chord***. The $^{n}$I chord requires specific attention given that it is the tonic chord which must be consonant and stable in order to reflect the tonality of the maqam when cadences end on it. This cannot be achieved with N3s in it because their roughness compromises the concordance and stability of the chord. Therefore, another combination of three scale tones are needed. Modern keyboard players play maqam music with 12 $_{EDO}$ and substitute chords that contain N3s with triads where the 3rd is suspended and the second or fourth are added instead; these are called $SUS^2$ and $SUS^4$ chords, respectively. These can be used sometimes, but they are not the most stable option. Schulter (2000) discusses how one of the most stable three note chords, made up of an octave split by a lower fifth and an upper fourth[1], was a standard of stable consonant concordance in European medieval polyphony; she calls this chord a trine. If we make the $^{n}$I chord a trine then it becomes: C-G-C, and can be signified with $I^t$, 't' for trine.

If we convert all the neutral triads in the fundamental scale to trines, then we will have solved the issue of wolf intervals, but our harmony will seldom have thirds and sixths in it. If we want to include more thirds and sixths, staples of colorful consonance, then we need to introduce non-scale tones again.

**5.3.2 Comma Shift Method**. In this method, we can introduce non-scale tones in the chords, but not in the melody. For the $^{n}$I chord, we can try to have a minor or major chord, instead of $I^t$. The triad of the $^{n}$I chord is made up of two primary field tones, C and G, and one secondary field tone, the E𝄳. If we seek to maintain as many scale tones as possible then it would be more optimal to change the E𝄳 to an Eb or E instead. These would yield a minor or major chord, respectively, but they are not reflective of the tonality of maqam rast. This reveals another property of harmony that I call *harmonic identity*: the harmony of a maqam must be reflective of the tonality of the

[1] Represented by the harmonics 2:3:4 in the harmonic series and one of the sonorities that al-Farabi classified as concordant (al-Farabi, n.d./1967, p. 179)

maqam. While monophonic tonality deals with melodic non-scale tones that interfere with the melodic establishment of a maqam's tonality, harmonic identity deals with harmonic non-scale tones that also interfere with the establishment of a maqam's tonality. Non-scale tones will not necessarily compromise harmonic identity, but they need to be used carefully to avoid that. Even though the melody plays E𝄳, a minor or major chord as the tonic chord of the fundamental scale will always pull the ear towards the minor or major tonality. If we were to change the C to C𝄳 or C𝄲 and the G to G𝄳 or G𝄲 to make a minor or major chord with the E𝄳 instead, then we will have compromised harmonic identity again; these hypothetical tonic chords are not reflective of the tonality of maqam rast with a tonic on C. Therefore, the $I^t$ remains the best option.

The 3 chord contains two secondary field tones, the E𝄳 and B𝄳, and one primary field tone, the G. Given that it is not a tonic chord, we can change G to G𝄲 to make an E𝄳 major chord: $350_c$-$750_c$-$1050_c$ in 24 $_{EDO}$. We can signify this chord as $3^M$ to indicate that it is a major chord built on the third scale degree which is a secondary field tone. The $^nV$ chord, in the same fashion, can change to a v chord: G-Bb-D; the Bb is part of jins nahawand on G, a traditional part of the sayr of maqam rast, and considered by some a scale tone to be used in descending melodic phrases. The $^n7^d$ chord can change to VII: Bb-D-F; the Bb is chosen because it maintains a common tone with the Bb in the v chord. Therefore, the chord progression in this tuning method becomes: $I^t$-$3^M$-IV-VII-ii-v. A sample of it can be listened to on my YouTube channel[1] (Maqam Harmony, 2024e) (see list of supplementary music examples).

[1] https://www.youtube.com/watch?v=5Axof-uZ9YY

***5.3.2.1 Comma Variant Analysis***. In the course of a musical work, when a pitch changes from one to another, we call it a pitch shift. If the pitch we shift to, the target pitch, is chosen premeditatively then the pitch shift is goal oriented, with the target pitch being the goal in mind. When the difference between two pitches is deemed a tuning issue to resolve or a tuning goal to achieve, that difference is called a comma[1]. Therefore, the difference between the first pitch and the target pitch = a comma. When we select a specific target pitch that a scale tone must shift towards, that target pitch is now called the comma variant of that scale tone (comma variant for short). The comma variant is meant to camouflage as its scale tone in chord progressions for the purpose of avoiding roughness or maximizing concordance. An example would be the previously stated G to G𝄲, and B𝄳 to Bb, where the comma is $50_c$, one step of 24 $_{EDO}$; G𝄲 is the comma variant of G, and Bb is the comma variant of B𝄳. Chords that have comma variant pitches are thus comma variant chords.

Table 1 summarizes the types of tones that can be used in maqam harmony that I have discussed in this paper. These tones differ in the goals behind using them. Scale tones are intended to be pitches of the current tonicized scale. Comma variants are intended to be deviations in pitch, by a comma, of scale tones. Because their goal is a harmonic comma-related one, comma variants are therefore non-sayr tones. Chromatic sayr tones are non-scale tones that are acceptable modulations or ornamentations based on the customs of modulation in maqam music. Lastly, chromatic non-sayr tones are

[1] Some also use “comma” to refer to any small interval. In this work I specifically use it in relation to a comma related goal or issue.

either unacceptable modulations or ornamentations that do not fit customs of modulation or tones arrived at by mistake or error.

**Table 1**

*The Types of Tones Used in Maqam Harmony*

| Diatonicism | Sayr | |
|---|---|---|
| | Sayr tones | Non-sayr tones |
| Within scale | Scale tones | Comma variants |
| Outside of scale | Chromatic sayr tones | Chromatic non-sayr tones |

***5.3.2.2 Perception of Comma Variants***. The effects of commas have not been specifically examined in music perception studies (Hubbard, 2021), but we can nonetheless draw some conclusions from related findings. Bharucha and Stoeckig (1986a) gave their participants an in-tune/out-of-tune decision task for target chords that were primed by a C Major triad tuned to 12 $_{EDO}$ in root position. The target chords were all triads in root position, began either six or seven semitones above the root of the prime chord, were either major or minor, related or unrelated to the prime chord, and in-tune or out-of-tune. The out-of-tune triads had a mistuned fifth that was lowered by $25_c$ ($700_c$-$25_c$ = $675_c$ fifth). Chords were considered related if they shared the same key or could belong to closely related keys that have many common tones. The prime chord was played for 3 seconds and followed immediately by 2 seconds of the target chord.

The eight total combinations were:

1. C Major to a Related in-tune G Major chord ($0_c$-$400_c$-$700_c$ to $700_c$-$1100_c$-$200_c$)

2. C Major to a Related out-of-tune G Major chord ($0_c$-$400_c$-$700_c$ to $700_c$-$1100_c$-$175_c$)
3. C Major to a Related in-tune A minor chord ($0_c$-$400_c$-$700_c$ to $900_c$-$0_c$-$400_c$)
4. C Major to a Related out-of-tune A minor chord ($0_c$-$400_c$-$700_c$ to $900_c$-$0_c$-$375_c$)
5. C Major to an Unrelated in-tune F# Major chord ($0_c$-$400_c$-$700_c$ to $600_c$-$1000_c$-$100_c$)
6. C Major to an Unrelated out-of-tune F# Major chord ($0_c$-$400_c$-$700_c$ to $600_c$-$1000_c$-$75_c$)
7. C Major to an Unrelated in-tune G# minor chord ($0_c$-$400_c$-$700_c$ to $800_c$-$1100_c$-$300_c$)
8. C Major to an Unrelated out-of-tune G# minor chord ($0_c$-$400_c$-$700_c$ to $800_c$-$1100_c$-$275_c$)

The authors tested the participants' accuracy and speed for the in-tune/out-of-tune decision task; the results indicated that accuracy and speed were highly correlated. The findings were also identical regardless of whether the target chord was major or minor. The most accurate and quickest decisions made were for the related in-tune target chords. This is because the prime chord creates an expectation of what the following chord should be based on the tonal hierarchies and musical repertoire that a listener is familiar with. The tonal hierarchy results when some scale tones gain more prominence and importance than others, like the tonic whose pitch becomes the central one that other tones are compared to and judged against (Krumhansl, 1990, p. 17). According to Krumhansl's principle of contextual distance, "two tones will be heard as more related when they occupy relatively high positions in the tonal hierarchy" (p. 148). A target chord or tone is perceived as belonging (high goodness of fit ratings) when preceded by a prime chord or tone that is related to it (Krumhansl, 1990). Furthermore, the perceived relatedness of two chords can occur even when they have no partials in common

(Bharucha & Stoeckig, 1986b), suggesting a strong link between expectancy and cognitive and tonal hierarchies. When the target chords are related and in-tune, they match exactly the chordal relationships listeners possess cognitively, which are themselves a result of familiarity. Deciding whether these chords are in-tune or not becomes very easy as such. The second most accurate and quickest decisions made were for the unrelated out-of-tune target chords. Due to familiarity creating an expectation of relatedness during chord movements, an unrelated chord from a distant key can violate this expectation, resulting in a perception that said chord does not belong, which makes it receive low goodness of fit ratings (Krumhansl, 1990). When target chords are both chromatic (from a distant key), and out-of-tune, it is easy to ascertain their out-of-tune-ness. The third most accurate and quickest decisions made were for the related out-of-tune chords. These are comma variant chords that confuse the listeners because they are also related to the prime chord and because their fifth is only lowered by $25_c$, making it difficult to ascertain their out-of-tune-ness. The most inaccurate and slowest decisions concerned the unrelated in-tune chords. Because they come from distant keys in relation to the prime chord, it makes them sound dissonant, but the fact that they are in-tune makes it difficult to ascertain whether that dissonance is due to mistuning or not.

Bharucha and Stoeckig’s (1986a) study revealed that listeners possess both tonal and tuning expectations. When tonal and tuning expectations are both satisfied, clarity is high. Likewise, when tonal and tuning expectations are both violated, clarity is high as well. This clarity results in quicker and more accurate responses about whether a target chord is in-tune or not. When either the tonal or tuning expectation is met, but not the other, the result is a lack of clarity; this is exemplified by the participants' slower and more inaccurate responses.

Studies of mismatch negativity (MMN) can shed light on perception of comma variants and chord progressions that have them. The MMN is a brain response elicited when the auditory system detects deviant sound stimuli in the presence of standard stimuli; this occurs unconsciously as well, even when subjects are not attentive to the sound stimuli (Bader, 2018, p. 442). In one study, participants listened to a melody and had MMN brain responses that were higher in amplitude when an out-of-tune pitch (by $50_c$) was perceived as opposed to an out-of-key pitch (by $100_c$), and this occurred even when they were preoccupied with reading a book (Brattico et al., 2006). Taken together, the studies of Bharucha & Stoeckig (1986a) and Brattico et al. (2006) show that a comma variant may be perceived as related if it is no more than $25_c$ away from its scale tone. This creates a lack of clarity as to whether the comma variant is in tune but does not lead to the perception that it is definitively out-of-tune. If the comma variant is $50_c$ away from its scale tone, however, then there is a higher chance that it would sound both unrelated and out-of-tune, leading to likely easier judgements of its in-tune-ness. We can extrapolate from these findings a relationship between the chord tones used in maqam harmony, and how they would likely be perceived when they follow a prime chord made up of scale tones; table 2 shows this extrapolation.

***5.3.2.3 Perception of Comma Shifts***. If comma variant chords are immediately preceded or followed by chords that contain the original scale tone of the comma variant, the result is called a comma shift progression. This is because the progression

**Table 2**

*Chord Tone Perception Based on a Preceding Chord Made Up of Scale Tones.*

| Perception | Chord tones in a subsequent chord classified based on their in-tune-ness and relatedness to preceding chord | | | |
|---|---|---|---|---|
| | In-tune scale tone [a] | Out-of-tune scale tone [b] | In-tune chromatic tone [c] | Out-of-tune chromatic tone [d] |
| Related | Yes | Yes | No | No |
| In-tune | Yes | Unclear | Unclear | No |
| Tonal expectation | Satisfied | Satisfied | Violated | Violated |
| Tuning expectation | Satisfied | Unclear | Unclear | Violated |

*Note*. This extrapolation is based on Bharucha and Stoeckig's (1986a) study where comma variants were mistuned by $25_c$ from their $12_{EDO}$ values.

[a] This is a common tone chord progression.

[b] This is a comma variant. Perception here is based on: JND $\leq$ comma variant $\leq 25_c$.

[c] This is a chromatic sayr tone.

[d] This is a chromatic non-sayr tone.

contains a direct comma shift from a scale tone to its comma variant or vice versa. These comma shift progressions can create a perception of mistuning and can sound jarring or "dubious" (Chan, 2022). MMNs were measured as higher in musicians and music students, as opposed to those with no musical training, in response to mistuned chords, suggesting that familiarity to a musical culture intensifies these perceptions of mistuning (Brattico et al., 2000). Garza Villarreal et al. (2011) conducted a study that showed that a triad consisting of a root, M3 ($400_c$), and a mistuned fifth of $750_c$ elicited an MMN because it violated the tuning expectations of the listeners.

From the perspective of auditory scene analysis theory, the best stream cohesion arises when the same pitch is preserved from one chord to the other in a common tone chord progression; the next best stream cohesion is when a voice's pitch moves by no more than a whole tone (Huron, 2001). It can therefore be concluded that comma shift progressions where a scale tone shifts by a comma of $50_c$, or vice versa, in the same voice will preserve the stream cohesion of that voice since the pitch movement is within two semitones. However, texturally, this kind of stream cohesion is not ideal for homophony. Accompanying voices are not expected to segregate, but rather to preserve the common tones. The early right anterior negativity (ERAN) is another brain response that, unlike the MMN, is specifically correlated with deviancy in the hierarchical rules of harmony, like chord succession rules in western music (Bader, 2018, p. 445). ERAN responses were stronger for chordal irregularities in homophonic chord sequences than they were for polyphonic ones (Koelsch & Sammler, 2008). This is because stream segregation is the norm in polyphony. In homophony, however, the accompaniment is expected to not segregate too much so that it does not compete with the melody voice. This reveals another property of harmony: *homophonic identity*. Comma variants and comma shifts are more perceptible in homophonic textures because there is a texture specific expectation for common tones to be preserved.

***5.3.2.4 Compromises of Comma Variants and Comma Shifts***. Comma variants and comma shifts both seek to preserve the concordance of important consonant intervals like the P5, M3, m3, and their inversions, but they compromise some maqam and harmony properties by doing so. Listening to the progression, a major chord on degree 3 is clearly acceptable, but it does cause some issues.

The more comma variants used, the more the maqam property of a small number of tones per scale is compromised. This results in a higher chance for an auditory working memory overload. Furthermore, when comma variants are introduced, a scale is no longer self-harmonizable. This reveals another property of harmony: *self-harmonizability*. Although it is a scale-specific property, I argue that it is also a property of harmony because it is a necessary condition to achieving harmonic tonality[1]: the emergent phenomenon from high vertical connectivity between scale tones. Comma variants can add new connections, but their presence alongside their scale tones hinders high connectivity. This is because they cannot connect to their scale tones, or vice versa, otherwise they produce a wolf chord. This property is also closely related to the property of harmonic availability. Essentially, the comma variant becomes an extra field tone that provides connections amongst tones in that field, but it will never connect to the other field. The result is good connections amongst primary field tones, good connections amongst secondary field tones, but never any good connections between the two fields. Comma variants also put difficulties on musicians to execute two versions of the same note a comma apart. The more comma variants there are the more difficulty musicians will face in performing them. Digitally, this is not a problem because machines are much more precise than humans.

Given that comma shifts are likely to be $50_c$ or less, they therefore compromise the maqam property of minimum scale step size. Comma shifts can also result in a perception of mistuning due to the auditory system detecting deviant unexpected pitch movements, a result from violations in tonal and tuning expectations, leading to MMN

[1] For other views of "harmonic tonality", see (Dahlhaus, 2014; Hearne, 2020).

brain responses. They can also lead to ERAN brain responses due to the violation of expectations regarding rules of harmony in homophonic textures, specifically the lack of preservation of common tones.

***5.3.2.5 Voice Leading the Commas***. Some listeners may not perceive a sense of mistuning from the chord progression example of this tuning method. Others, however, will perceive mistuning due to the G in the first chord shifting by a comma to a G𝄰 in the second chord, in the same voice, yielding a comma shift progression. These comma shifts can be encountered frequently in homophonic chord progressions of microtonal scales. We can either let the comma shift occur within the same voice, arrange it for two different voices, or avoid it altogether.

To embrace comma shifts in the same voice, they can be disguised by placing them in the inner voices. This is because outer voices are more perceptible than inner voices. However, even this can lead to a perceptibly jarring comma shift. The best practice that will help disguise a comma shift in the same voice is interval voice leading through contrary motion. This is achieved when the interval movement from the first chord to the second is in contrary motion and the chords resolve on a concordant chord. An example would be the vertical interval G-C (P4) moving to G𝄰-B𝄳 (M3). The M3 should ideally be tuned to 5/4 ~$386_c$. Generally, movements between a P4 and a 5/4 M3, even in similar motion, can disguise a comma shift well.

To arrange it for two different voices, we can borrow from the compositional approach of poly-maqam; to treat each voice as an independent one that is not allowed to use melodic development that is not in accordance with its sayr. In a comma shift progression, a comma variant differing from its scale tone by less than $50_c$, but more than the JND, will neither be perceived as a common tone nor as an acceptable sayr tone because maqam rast does not have a $50_c$ step. If we seek to preserve the voice leading rule that forbids part crossing, then one voice can play the scale tone in one octave while another voice plays its comma variant in a different octave.

To avoid the comma shift altogether, we simply avoid playing a scale tone and its comma variant in succession. To do this, we can remove one of these tones from a chord or avoid playing the two chords altogether. To preserve the two chords, however, we can add an intervening chord in the middle. This passing chord has no common tones with the first chord and no comma shifts with the third chord. Frequent use of this will lead to homorhythmic homophony, a texture that uses more chords and thus provides more opportunities to use these intervening passing chords to avoid comma related common tones.

In general, to disguise comma variants and comma shifts, they should ideally be employed in different voices, different octaves, metrically unstressed positions, and if restricted to one voice then in the inner voice, using stepwise contrary motion, concordant intervals, and passing chords if needed (to avoid comma related common tones), with vibrato (Prame, 1997), less intensity, less duration (van Besouw et al., 2008; Vos, 1982), faster tempo (Burns, 1999), and in different parts of the stereo field (Giedraitis, 2019, p. 121). These interventions will help in masking comma variants, comma shifts, and other concerns related to perceptions of mistuning.

**5.3.3 Tonic Drift Method**. This method arises as a natural response to the issues of the comma shift method. In this method, pitch shifts of any kind are not allowed, and common tones must be preserved. This means that, to preserve common tones, we can either use a scale tone or its comma variant; we cannot comma shift between them. This immediately forces us to choose one or the other. For example, the $I^t$ chord possesses a G, and the subsequent $3^M$ chord a G‡. Suppose we choose the G‡. The $I^t$ chord cannot be changed to $1^t$ because a trine on C‡ (C‡-G‡-C‡), although concordant in and of itself, is not the real tonic of maqam rast C. If we were to do that then the tonic will drift, hence the name of this method. This compromises the tonic stability property of maqam and is therefore unacceptable. We must choose G instead. Choosing G preserves the $I^t$ chord but forces us to change the $3^M$ chord to an E minor or Eb major chord so that the G can be preserved from the $I^t$ chord to the next. This means that the E𝄳 in the $3^M$ chord must either change to E or Eb so that the E minor or Eb major chord can be formed. Once we make either choice, harmonic identity will be compromised because the E and Eb will make the tonality drift towards major or minor, respectively[1]. Therefore, this is also unacceptable.

When it comes to the tuning of the sayr voice, we have two choices: either we let it conform to the tuning of the chord progression or allow it to be free. Suppose we make it conform to the tuning of the chord progression. If the progression uses an Eb or E then the melody will have to as well, but that would immediately compromise jins identity; the N2 steps of jins rast will be replaced by a M2 and a m2 when Eb or E

[1] The E𝄳 is the characteristic pitch of maqam rast; losing it compromises the identity of the root jins of the maqam.

replace E𝄳. Suppose we allow the sayr voice tuning to be free. If the sayr voice plays an E𝄳 the entire melody then the second chord would contain an E𝄳 in the melody and an E or Eb in the chord below, yielding a wolf octave, and thereby compromising the concordance of 8ves. If the sayr voice only plays the E and Eb at the same onset as their corresponding chord and an E𝄳 for the rest of the melody then sayr voice tuning profile consistency will be compromised. Jins identity, and acceptable use of non-scale tones will probably also be compromised. Due to these compromises, this tuning method is unacceptable.

Tonic drift has been discussed extensively in the context of JI as the byproduct of preserving just intervals, avoiding non-just or mistuned vertical intervals, and avoiding pitch shifts (Erlich, 2001; Giedraitis, 2019; Howard, 2007; Parncutt & Hair, 2018 ). Howard (2007) reported that a choir quartet indeed sang in JI and that there was a measurable tonic drift. Due to the tonic drift issue, some recommend the use of comma variants and shifts instead (Kimber, 1974).

**5.3.4 Tempering Method**. In this method, we cannot have comma variants, pitch shifts, or tonic drift. We can only work with scale tones. This method has the advantage of self-harmonizability. Since our original scale tones do not allow the preservation of common tones due to wolf intervals, we must therefore adjust the pitches of the scale. As discussed before, if we change the E𝄳 in jins rast to an E or Eb then jins identity will be compromised because the two N2s will no longer be neutral. Suppose we change E𝄳 not to $400_c$, but to 5/4 ($\sim 386_c$) instead. 5/4 is the M3 in the harmonic series, represented by the harmonics 4:5 and would thus form the triad 3:4:5 with C and G. This is the most concordant triad, but it would make the intonational profile of jins rast very close to that of the Turkish one. To the Arab audience, this intonation would sound like major or ajam instead of rast, and this would therefore, again, compromise the jins identity of rast.

To temper means to reduce the size of a comma down to zero. Tempering means to resolve the issue of having comma variants altogether by either only choosing the scale tone, only choosing the comma variant, or only choosing some value in between them as a compromised solution. We cannot choose the $700_c$ G, for example, because we would have achieved nothing; it cannot harmonize with E𝄳. Suppose we choose the $750_c$ G instead. It would harmonize with E𝄳, but a fifth of $750_c$ is so far from the original $700_c$ G that it would compromise the identities of all the intervals that G forms with the other scale tones. We can choose some value in between, but at this point in the analysis we do not have the knowledge on how to choose a pitch for G out of many potential possible ones that do not compromise the interval and jins identities of the scale. I will return to this method after careful analysis of the literature on perception of intonation and categorical perception.

**5.3.5 Adaptive Just Intonation Method**. In this method, tonic drift is not permissible, and every vertical interval must be in JI. Pitch shifts are allowed, however. Unlike the comma shift method, the tuning of the sayr voice is permitted to pitch shift. A comma can be divided so that instead of a full comma shift, shifts by fractions of a comma can take place. These fractional comma shifts can be quite imperceptible if the difference in cents is small. However, this does require pitch shifts in the sayr voice so that every chord can be in JI and so that tonic drift is avoided. As discussed in the tonic drift method, changes in the tuning of the sayr voice compromise the sayr voice tuning profile consistency property of maqam and potentially jins identity as well; they are unacceptable as such. We can proceed with this method under the condition that the sayr voice tuning must remain consistent.

Because this method demands that every chord be in JI, it means that we must depart from $24_{EDO}$ tuning. Instead of $400_c$ being our M3 between E𝄳 and G𝄲, it now must be a ratio of 5/4 or ~$386_c$. We can also change our sayr voice tuning from $24_{EDO}$ by adopting cent values that form small integer ratios with the tonic (C), like the 11/9 (~347c) for the E𝄳 and 11/6 (~1049c) for the B𝄳. However, even though these are small(er) integer ratios, which can deceive proponents of mathematical ratio-based theory of consonance as being concordant intervals, they nonetheless still have psychoacoustic roughness in the low to middle end of the spectrum. They also barely deviate from $24_{EDO}$ values and thus offer nothing new. Mathematical ratio-based theories cannot be used as the sole explanations for harmony, intervals, and intonation (Abu Shumays, 2009; Parncutt & Hair, 2018; Pfordresher & Brown, 2016).

We can keep the sayr voice tuning in $24_{EDO}$ and gather comma variants, to be used in the other voices, that form JI intervals with it. Therefore, G𝄲 = E𝄳 ($350_c$) + $386_c$ = $736_c$. Our comma between G ($700_c$) and G𝄲 ($736_c$) is now = $36_c$, much less than $50_c$. This method effectively becomes another version of the comma shift method, with the added condition that all chords need to be in JI. Instead of a full $50_c$ comma shift, however, a $36_c$ comma shift is used for the 5/4 M3 and a $34_c$ comma shift is used for the 6/5 m3 (~$316_c$). A sample of the chord progression in this comma shift + JI method can be listened to on my YouTube channel[1] (Maqam Harmony, 2024d) (see list of supplementary music examples).

Because chords in this method can only be in JI, this requires us to likely gather a comma variant for every scale tone so that every chord can be in JI (Erlich, 2001). Although the commas in this method are smaller than the ones used in the 24 $_{EDO}$ comma shift method, they will occur more frequently due to the constraint that every chord need be in JI. The more comma variants and comma shifts, the more prevalence of the perception issues related to them that were discussed earlier.

**5.3.6 Adaptive Tuning Method**. In this method, both horizontal intervention in the form of pitch shifts, as well as vertical intervention in the form of chord mistuning are allowed so that we can alleviate compromises in tonic drift, pitch shifts, and chord concordance. This method resembles what choirs and barbershop quartets do. We can avoid the constraint of every chord needing to be in JI and only add comma variants to chords we deem not sufficiently concordant. This can mean a lot less comma variants, but like the comma shift and adaptive JI methods, it nonetheless relies on comma variants and therefore leads to the array of issues that come with them. Large EDOs like 217 $_{EDO}$ have been recommended for adaptive JI and adaptive tuning because they allow for both 5-limit JI chords and imperceptible fractional pitch shifts (Monzo, 2005a). However, as stated before, computers are much better at handling goal-oriented small pitch increments and shifts than musicians. Many software programs have been developed to deal with the concordance, pitch shifts, and tonic drift issues of JI in

[1] https://www.youtube.com/watch?v=lywzheyTcO8

western music (Giedraitis, 2019; Stange et al., 2018). If we want a solution that is applicable past digitally made music, then we cannot rely solely on this method either.

## 6. Examining the Literature on Music Perception

If we want a solution that forgoes the use of too many comma variants, preserves concordance, and maximizes self-harmonizability, then we need to temper the fundamental scale. In tempering, we change the melodic intervals of a scale so that we can preserve some properties while compromising others. It’s a process of scale construction where these properties act as constraints. By acting as constraints, the many maqam and harmony properties I have identified help to reduce the large problem space of having too many possible theoretical temperaments to choose from. However, the constraints also act as barriers for potentially suitable temperaments, sometimes making it seem as if there are no options available at all. The literature on intonation in performance, perception of intonation, and categorical perception can perhaps shed light on why some intonations are acceptable, why others are not, and how we can create temperaments with acceptable compromises that conform to the properties of maqam, harmony, and to the findings.

### *6.1 Intonation is Variable*

Intonation is approximate, uncertain, and fuzzy (Abu Shumays, 2009; Parncutt & Hair, 2018). The literature on intonation in melodies played by non-fixed pitch instruments in music that is judged as good or excellent shows typical variation by at least $\pm 10_c$ (Parncutt & Hair, 2018). String instruments, for example, can use a lot of vibrato, which generates more intonation variation; some findings report dispersions of

40 to $60_c$ from theoretical values (Fyk, 1995; Shackford, 1962, cited in Knipper & Kreutz, 2013). When it comes to microtonal music, Knipper and Kreutz (2013) measured the intonation of string instruments in recordings for the same piece of music written for third-tone tuning and found that the measured values deviated between $14_c$ to $42.5_c$ from theoretical values, and that these deviations were nonetheless in available commercial recordings. Delviniotis et al. (2008) recorded an average of $30_c$ deviation in the intervals of expert singers of byzantine chant when they were asked to sing ascending and descending scales.

### *6.2 Intonation is Not Random*

Despite a lot of evidence that intonation can deviate by large amounts from theoretical values, it is not random or entirely arbitrary. For example, Fyk (1995) showed that expressive variation in intonation by violinists is intentional to achieve desired goals related to tonal functions, directions of intervals, and harmonic tension. Expressiveness is thus a collection of intonational goals.

The musical context also influences performers' intonation of intervals (Bader, 2018, pp. 645-646). Performers listen and perceive the previous pitches that they have intoned as they intone the next pitches. This dynamic feedback process from perception to production underlies the fact that intonation is not random. Compared with tuning intervals in isolation, musicians tune intervals closer to the targets asked of them in conditions where musical context is provided (Rakowski, 1990). Pfordresher and Brown (2016) found that singers produced inaccurate intervals, but that they were nonetheless very good at preserving the “ordinal integrity” of the intervals in the song (ex: first interval-second interval is larger-third interval is smaller than the second-etc.).

There is also a tendency to prefer stretching of melodic intervals larger than a P4 or P5, including the P5, and contraction of intervals that are smaller. Rakowski and Miskiewicz (1985) found that participants had a preference to contract intervals smaller than a P4 in comparison to 12 $_{\text{EDO}}$ values and to expand larger intervals. Vurma and Ross (2006) had professional singers perform m2, tritone, and P5 intervals and found that the singers generally sang the minor seconds narrower than 12 $_{\text{EDO}}$ while the P5s were sung wider, both when ascending and descending. Rosner (1999) also showed that musicians prefer larger intervals stretched and smaller intervals compressed during a listening task. These tendencies are related to the previously discussed gestalt properties of auditory scene analysis, that stream cohesion is best reinforced by contracting intervals smaller than a P4; it therefore follows that stretching of intervals larger than a P4 is a way to provide extra contrast and clarity to them by creating even more stream segregation. These findings can also be traced to another established one in the literature, that listeners tend to prefer a stretched melodic octave as well (Dobbins & Cuddy, 1982; Hartmann, 1991; Hubbard, 2021).

***6.3 Perception of Intonation as In-Tune***

If there is consistent intonational deviation from theoretical values, how is that deviation judged by listeners? It turns out that even when intonation is out-of-tune compared with theoretical values, it can nonetheless be in-tune perceptually and aesthetically. Professional singers were asked to sing melodic intervals and then rate each other’s singing in terms of in-tune-ness (Vurma & Ross, 2006); they accepted melodic intervals that were 20-25$_c$ away from theoretical values as in-tune. Listeners can also accept deviations as much as 70$_c$ as in-tune but are much more tolerant when these deviations are sharp as opposed to flat (Deutsch, 1998, p. 248).

Aside from vibrato, tempo, and duration, mentioned in the voice leading of the commas section, timbre also plays a role in perceptions of mistuning. Geringer et al. (2015) found that participants had more tolerance for intonation errors when they were committed by the human voice, then the violin, and then the trumpet, in that order. Hutchins et al. (2012) also found that participants were 40% more likely to perceive a sung note as in tune compared to the same note played by a violin.

### *6.4 Categorical Perception*

How much of this intonational variation tolerance relates to musical intervals? Answering this question will allow us to figure out the amount of tempering that preserves interval identity, the essential melodic information of an interval. As Parncutt and Hair (2018) reasoned, the literature from empirical studies shows that intervals can be perceived as in-tune even when they are actually out-of-tune theoretically. Human beings have a remarkable ability to hone in on the intended intervals and forgive mistuning. Interval perception does not have high resolution; many sizes of an interval may be perceived as the same interval (Deutsch, 1998, p. 257).

**6.4.1 Musical Training and Categorical Perception**. A robust finding in the literature is that those who have musical training always perform better than those who do not in interval identification and discrimination tasks (McDermott et al., 2010;

Zarate et al., 2012). For example, they are better at interval discrimination in tasks where the third in a triad is mistuned by several different increments (Locke & Kellar, 1973). Musical training is indicative of more familiarity with the music related variables being studied. Comparing results of musically trained and non-musically trained participants sheds light on whether a research finding can be generalized past musical familiarity or not.

**6.4.2 Tuning System and Categorical Perception**. These findings generally come from studies on western participants and western music. The evidence that musically trained persons perform better than those who are not is specific to the music they were encultured with, western music in 12 $_{EDO}$. Those who have western music training will therefore perform better at identification and discrimination tasks of 12 $_{EDO}$ intervals because they learn the interval names during their training, and spend more time listening to, performing, and tuning their instruments closer to their 12 $_{EDO}$ theoretical values. As such, they develop more cognitively entrenched categories of the intervals. This can be confirmed by studies on how internal rehearsal can improve working memory for tones. Studies that used 12 $_{EDO}$ tones the participants were familiar with showed that internal rehearsal improved performance while studies that used non-12 $_{EDO}$ tones showed that it did not (Bader, 2018, p. 463).

What happens when participants musically trained in 12 $_{EDO}$ are asked to identify intervals that are not in 12 $_{EDO}$? We can reason that they would either be poor at identifying them or identify them as mistuned versions of the nearest 12 $_{EDO}$ interval category they are familiar with (Bader, 2018, p. 646). The latter is exactly what happened when Burns and Ward (1978) asked musicians to identify what a 24 $_{EDO}$

neutral third ($350_c$) interval was. The musicians quickly identified the neutral third as either the 12 $_{EDO}$ m3 ($300_c$) or M3 ($400_c$). They also identified the 24 $_{EDO}$ $450_c$ interval as either a M3 or P4 ($500_c$). The authors concluded that intervals are perceptual categories with widths close to a semitone ($100_c$), one step of 12 $_{EDO}$. This means that each interval in 12 $_{EDO}$ has a $\pm 50_c$ perceptual range for a total perceptual width of $100_c$. The reality is that intervals are indeed perceptual categories, but the widths of these categories entirely depend on enculturation and familiarity. I hypothesize that had the authors tested Arab musicians instead, the musicians would categorize the neutral melodic intervals into 24 $_{EDO}$ interval labels because the intervals of 24 $_{EDO}$ are among the intervals taught in standard Arabic music education.

**6.4.3 The Perceptual Scale: 48 $_{EDO}$.** We can infer from the findings of Burns and Ward (1978) that for 12 $_{EDO}$, the perceptual range = (one step of 12 $_{EDO}$ $100_c$ ) ÷ 2 = $\pm 50_c$. The perceptual width for any 12 $_{EDO}$ interval is $50_c + 50_c = 100_c$. Therefore, for the $200_c$ M2 interval, for example, the perceptual range would be $200_c \pm 50_c$. The perceptual boundaries are thus the endpoints of the perceptual range; thus $200_c \pm 50_c = 150_c$ and $250_c$. The perceptual category of the M2 interval is thus 150-$250_c$. We can now calculate the relevant perceptual ranges for the Arab 24 tone system, represented by 24 $_{EDO}$. The perceptual range of 24 $_{EDO}$ = (one step of 24 $_{EDO}$ $50_c$) ÷ 2 = $\pm 25_c$. The perceptual width for any 24 $_{EDO}$ interval is $25_c + 25_c = 50_c$. The perceptual range for any interval in 24 $_{EDO}$ is therefore the value in cents of that interval ± the perceptual range of 24 $_{EDO}$; ex: for the $350_c$ N3 interval, the perceptual range is $350_c \pm 25_c$. The perceptual boundaries of the $350_c$ interval are the endpoints of its perceptual range, thus $350_c \pm 25_c$

= $325_c$ and $375_c$. The perceptual category of the N3 interval in 24 $_{EDO}$ is thus 325-$375_c$. We can now refer to this simply as the perceptual N3.

This perceptual range of $\pm 25_c$ can easily be represented by 48 $_{EDO}$ and is exactly what von Hornbostel (1906) used to group the values of intervals that he measured from phonograph records of Tunisian performances. For example, he considered all values he retrieved that are between $275_c$ and $325_c$ as minor thirds, and all values between $325_c$ and $375_c$ as neutral thirds[1].

**6.4.4 Evidence for the $\pm 25_c$ Perceptual Range**. Even though the $\pm 25_c$ perceptual range was extracted out of analysis of 24 $_{EDO}$ intervals, it nevertheless has evidence in western studies of 12 $_{EDO}$ music as well, like the findings from Bharucha and Stoeckig (1986a) and Vurma and Ross (2006) that were previously discussed. Larrouy-Maestri (2018) also discovered that listeners, whether musically trained or not, can only tolerate approximately $25_c$ of mistuning in melodies; this was for both tones and intervals. Zarate et al. (2012) found that musicians had improved interval discrimination beginning at interval differences of $100_c$, but that non-musicians only showed improved discrimination at interval differences beginning at $125_c$. This shows that non-musicians have more tolerance for intonation variation and that their lack of musical training in 12 $_{EDO}$ forces them to need an extra $25_c$ in order to be certain about interval identification and discrimination. Even a soprano that is widely agreed upon as being very good can be off from the accompaniment by $25_c$ (Geringer et al., 2015).

[1] Interestingly, Von Hornbostel stated that 24 $_{EDO}$ was used as a scheme to group the values, but then immediately listed values like $275_c$ and $325_c$ which are from 48 $_{EDO}$.

**6.4.5 Intonation Hypothesis: Perceptual Identity**. Let us list the main findings regarding intervals in the following points:

1. Intervals are perceptual categories as opposed to combinations of exact pitches or frequencies (Pfordresher & Brown, 2016; Parncutt & Hair, 2018).
2. Perceptual categories emerge from a person's familiarity with a specific tuning system (Bader, 2018, p. 463; Loosen, 1994; Loosen, 1995).
3. Each perceptual category has a perceptual range based on the nearby categories the person is already familiar with. The further the nearby categories are, the larger the perceptual range of the interval.

   We can also add one more finding:
4. Perceptual categories can overlap each other (Pfordresher & Brown, 2016).

I will now work through an example that demonstrates all these findings. Let us take the melody: $0_c$-$215_c$-$425_c$-$535_c$-$750_c$. This is a simple stepwise ascending melody that is supposed to intone the major scale in 12 $_{EDO}$. Each successive pitch forms a whole tone or semitone that is within a $\pm 25_c$ perceptual range with the pitch before it. However, the intonational variation accumulates that by the time we are at the fifth note, it is no longer a P5 away from the first note. This $750_c$ pitch now overlaps with the neutral augmented fifth in 24 $_{EDO}$, as opposed to the $700_c$ P5 of 12 $_{EDO}$.

I hypothesize that an intoned pitch stands the best chance of being judged as in-tune the more it falls within the corresponding perceptual categories of all the notes it forms intervals within the immediate context. The more this property is preserved for all notes of a scale, the more the perceptual identity of the scale will be preserved.

## 7. Tempering Revisited

Now that we have examined the literature on music perception, we can redefine some of our properties more clearly. For interval identity, the essential melodic information of an interval is preserved within its perceptual boundaries; this allows for the categorization of the interval. Interval identity is thus preserved when the interval is within its $\pm 25_c$ perceptual range. Jins identity is therefore preserved when the perceptual identities of its steps are preserved as well as their ordinal integrity.

### *7.1 The New Perceptual Fundamental Scale*

Based on the perceptual scale of 48 $_{EDO}$, the new perceptual fundamental scale of maqam rast C, represented by the perceptual categories of its 24 $_{EDO}$ notes, is: 0-(175-225$_c$)-(325-375$_c$)-(475-525$_c$)-(675-725$_c$)-(875-925$_c$)-(1025-1075$_c$). I will refer to this as the inherent perceptual fundamental sale, 'inherent' for short.

We can also represent the fundamental scale in the form of its perceptual steps. Since the fundamental scale's steps are: M2-N2-N2-M2-M2-N2-N2 then the scale becomes: 0-(175-225$_c$)-(125-175$_c$)-(125-175$_c$)-(175-225$_c$)-(175-225$_c$)- (125-175$_c$)- (125-175$_c$). I will refer to this as the relative perceptual fundamental scale, 'relative' for short. Most, if not all, intonational profiles of the fundamental scale in the Arab region can be accounted for through these conceptualizations.

### *7.2 How We Got Here: A Recap of the Problems*

I will now recap the problem-solving chain of thought that has gotten us here thus far for harmonizing maqam rast C in homophonic textures, with the following points:

1. *Concordance Problem*. Mixing the primary and secondary field tones of the scale yields chords that have high psychoacoustic roughness.
2. *Harmonic Availability Problem***.** The two secondary field tones thus only have each other as harmonizable options. This lack of harmonic availability for the secondary field tones leads to forced leaps in voice leading which are not conducive to preserving the maqam property of stepwise melodic development. Non-scale tones are thus required to provide harmonizable options.
3. *Comma Variants Problem*. When a comma variant is chosen for the scale tone G, the triad of the third degree becomes complete, but the presence of both G and its comma variant creates many compromises in the properties of maqam and harmony.

To avoid the compromises of comma variants, we must choose a value for G that can become both the chord tone for the E𝄳-G-B𝄳 chord, as well as the scale tone for every melodic instance of G.

The *tempering constrains* therefore become:

1. Choose cent values for the notes in the chord E𝄳-G-B𝄳 such that the result is a concordant chord.
2. Choose a value for G that falls within the perceptual range of G in both the inherent and relative versions of the perceptual fundamental scale.
3. Temper the other scale degrees such that each step is preserved in accordance with both versions of the perceptual fundamental scale.

4. Temper the other scale degrees to maximize concordance of either 3rds, 5ths, or both.

### *7.3 Framework Selection: Which EDO?*

Before we implement the plan outlined above, we need to select an appropriate framework from which we can choose cent values for the perceptual intervals of the two versions of the fundamental scale. Since each interval's perceptual width is $50_c$, we have 50 potential values to choose from for each interval. 24 $_{EDO}$, however, only gives us one choice for that range, the $50_c$ step. Similarly, 48 $_{EDO}$ only gives us two choices, the $25_c$ and $50_c$ steps. We therefore need a larger framework that provides many options to choose from so that we can have many different attempts at the solution.

If we want to access the same steps of an EDO but in a larger one, we simply need to multiply the EDO number by 2, 3, 4, etc. For example, 12 $_{EDO}$ × 2 = 24 $_{EDO}$, which possesses all the steps of 12 $_{EDO}$ plus an additional 12 that lie exactly halfway in between. Since 48 $_{EDO}$ has all the pitches of 24 $_{EDO}$, and since the perceptual range of 48 $_{EDO}$ is $\pm 25_c$, it is thus able to give us all the cent values of 24 $_{EDO}$ intervals along with their perceptual interval boundaries. Therefore, multiplying 48 $_{EDO}$ by 2, 3, 4, etc. will allow us to reach higher EDOs that have all the aforementioned cent values along with other values in between[1].

[1] Many different EDOs and arbitrary values can provide the pitches that fall within the perceptual ranges of the intervals we need, but an EDO that possesses the $25_c$ and $50_c$ steps will provide both the original 24 $_{EDO}$ values along with their perceptual boundaries and is thus simply chosen for the ease of transmission of my theoretical ideas. Just like the harmonic series, EDOs are not systems that have inherent idealistic value; they are simply tools for tuning and education. It is humans who attach idealistic values to them.

***96 $_{EDO}$***. The first option is 48 $_{EDO}$ × 2 = 96 $_{EDO}$. In this EDO, we have both the $25_c$ and $50_c$ categorical boundary markers. Every $50_c$ has five pitches to choose from, ex: $350_c$, $362.5_c$, $375_c$, $387.5_c$, and $400_c$. However, each $25_c$ step only has one pitch in between, ex: $0_c$, $12.5_c$, $25_c$. Because it only offers one extra option in between every $25_c$ step, this EDO will thus be restrictive for meeting tempering constraints 3 and 4.

***144 $_{EDO}$***. The second option is 48 $_{EDO}$ X 3 = 144 $_{EDO}$. In this EDO, every $50_c$ step has seven pitches to choose from, ex: $350_c$, $358.3_c$, $366.7_c$, $375_c$, $383.3_c$, $391.7_c$, and $400_c$. This EDO should provide enough options for different sizes of jins rast's melodic steps (and thus sevenths) as well as different sizes of thirds (thus sixths) and fifths (thus fourths). This EDO was first described by Abu Nasr al-Farabi, the medieval philosopher and musicologist, in his Kitab al-Musiqa al-Kabir (The Great Book of Music) where he specifically described the ajnas in terms of equal steps of 144 $_{EDO}$ (al-Farabi, n.d./1967, pp. 150-157)[1]. One step of 144 $_{EDO}$ has been given the unit name "farab" (Huygens-Fokker Foundation, 2023; Monzo, 2005b). Thus, 1/144 = $8.3_c$ = 1 farab. I will use this unit in my analysis to easily refer to one step of 144 $_{EDO}$.

### *7.4 The Solution: Optimization*

The problem can be conceived of as a mathematical optimization problem. Fortunately, it is not so complex so as to require an algorithm to generate solutions. The constraints are the maqam and harmony properties that I have identified as well as the four tempering constraints. Given that we have defined our tempering constraints clearly, we will start by satisfying constraint 1 but immediately discover compromises

[1] I discovered this fact, which gave me profound pleasure, mere months after I had already set out my work in 144 $_{EDO}$.

and setbacks in the other constraints that then require us to keep generating solutions in an iterative way. I will be using the $24_{EDO}$ maqam rast C as a starting point: $0_c$-$200_c$-$350_c$-$500_c$-$700_c$-$900_c$-$1050_c$.

**7.4.1 Jins Harmonic Sika**. For G to be concordant with E𝄳 and B𝄳, it necessarily must not make N3s with either of them. This means that the two N3s must each become either a m3 or a M3 instead. The question then becomes: are the m3 or M3 able to become the outer interval of jins sika[1] whilst preserving its identity? Jins sika in maqam rast C is E𝄳-F-G.

We begin with the m3. The available m3s that satisfy its perceptual identity in $144_{EDO}$ are $300_c \pm 25_c$, giving us the options: $275_c$, $283.3_c$, $291.7_c$, $300_c$, $308.3_c$, $316.7_c$, and $325_c$. The lower end of this range is very far from the lower boundary of a N3: $350_c - 25_c = 325_c$. Therefore, we begin surveying the options from the higher end. The $325_c$ option is the closest to a N3, overlapping directly with its lower boundary, but is not concordant vertically; It is $9.3_c$ away from the 6/5 ($315.6_c$) harmonic series m3. This much vertical mistuning towards the neutral zone will result in psychoacoustic roughness. The next option is the $316.7_c$ m3, which is only off from 6/5 by $\sim 1_c$. This makes it very ideal vertically, but it is outside the perceptual range of the N3. Nevertheless, it is only outside its range by one farab. The other options are even further from the perceptual range of the N3, which rules them out immediately, as there will be

[1] In English, we simply refer to it as jins sika, without the need to clarify that it is a trichord made up of three notes; that information is assumed obvious. The word jins is used to refer to all the ajnas in maqam music.

too much loss in the interval identity of the N3. Having been restricted to the $316.7_c$ m3, let us see if it can host steps that preserve jins sika's identity.

Jins sika is made up of a lower N2 followed by a M2. In 144 $_{EDO}$, the N2 options are: $125_c$, $133.3_c$, $141.7_c$, $150_c$, $158.3_c$, $166.7_c$, and $175_c$. The M2 options are: $175_c$, $183.3_c$, $191.7_c$, $200_c$, $208.3_c$, $216.7_c$, and $225_c$. We begin by subtracting the median N2 from $316.7_c$: $316.7 – 150_c = 166.7_c$. This is outside the perceptual range of the M2. This also means that any values higher than $150_c$ for the N2 will also yield a M2 outside its perceptual range. Next: $316.7_c – 141.7_c = 175_c$, which is within the perceptual range of the M2. $316.7_c – 133.3_c = 183.3_c$, also within the perceptual range of the M2. Finally, $125_c$ is the lower boundary of the N2 and will thus be the last N2 value we subtract: $316.7_c – 125_c = 191.7_c$, also within the perceptual range of the M2. $125_c$ provides a good intonation of the N2 for some ajnas and songs, like certain profiles of bayati and saba, but because it coincides with the upper perceptual boundary of the m2, it may not be sufficiently neutral enough for the intonation of jins sika in the fundamental scale. We thus emerge with two ideal versions of the $316.7_c$ m3 jins sika: $141.7_c$-$175_c$ and $133.3_c$-$183.3_c$ where the outer interval is a concordant m3 (one farab away from the lower boundary of the N3) and the inner steps fall within their respective perceptual ranges. Because the outer interval is a concordant m3, I call this the m3 jins harmonic sika.

Let us use the same process to see if an outer M3 can also generate jins harmonic sika. The available M3s that satisfy its perceptual identity in 144 $_{EDO}$ are $400_c$ $\pm 25_c$, giving us the options: $375_c$, $383.3_c$, $391.7_c$, $400_c$, $408.3_c$, $416.7_c$, and $425_c$. This time, the higher end of this range is very far from the upper boundary of a N3: $350_c$ + $25_c = 375_c$. Therefore, we begin surveying the options from the lower end. The $375_c$

option is the closest to a N3, overlapping directly with its upper boundary, but is not concordant vertically; It is $11.3_c$ away from the 5/4 (386.3c) harmonic series M3; this much vertical mistuning towards the neutral zone will result in psychoacoustic roughness. The next option is the $383.3_c$ M3, which is only off from 5/4 by $3_c$. This makes it very ideal vertically, but it is outside the perceptual range of the N3. Nevertheless, it is only outside its range by one farab. The other options are even further from the perceptual range of the N3, which rules them out immediately, as there will be too much loss in the interval identity of the N3. Having been restricted to the $383.3_c$ M3, let us see if it can host steps that preserve jins sika's identity

We subtract the median N2 ($150_c$) from $383.3_c$ and retrieve the value $233.3_c$. This is outside the perceptual range of the M2. This also means that any values lower than $150_c$ for the N2 will also yield a M2 outside its perceptual range. Next: $383.3_c$ – $158.3_c$ = $225_c$, which is within the perceptual range of the M2. $383_c$ – $166.7_c$ = $216.7_c$, also within the perceptual range of the M2. Finally, $175_c$ is the upper boundary of the N2 and will thus be the last N2 value we subtract: $383.3_c$ – $175_c$ = $208.3_c$, also within the perceptual range of the M2. Because it coincides with the lower perceptual boundary of the M2, $175_c$ may not be sufficiently neutral enough for the intonation of an Arab jins sika in the fundamental scale. We thus emerge with two ideal versions of the $383.3_c$ M3 jins harmonic sika: $158.3_c$-$225_c$ and $166.7_c$-$216.7_c$ where the outer interval is a concordant M3 that is one farab away from the upper boundary of the N3, and the inner steps fall within their respective perceptual ranges. Table 3 shows all the retrieved versions of jins harmonic sika.

What is clear from the tempering process so far is that in order to gain a concordant third between E𝄳 and G, we will have to compromise the concordance of the fifth between C and G. This means that we are proceeding in a meantone-like approach where we seek to maximize concordance in 3rds that result in compromises in the concordance of 5ths.

**Table 3**

*Jins Harmonic Sika in 144 $_{EDO}$ Steps.*

| m3 Jins harmonic sika | M3 jins harmonic sika |
|---|---|
| $141.7_c$ - $175_c$ | $158.3_c$ - $225_c$ |
| $133.3_c$ - $183.3_c$ | $166.7_c$ - $216.7_c$ |

**7.4.2 Transposing Jins Harmonic Sika.** Let us now tune jins sika in the fundamental scale to the versions of jins harmonic sika that we retrieved. Because showing the tuning steps is a lengthy process, I will only work with one of the ajnas in table 3 and then discuss how the same process can be applied for the other ajnas afterwards. I will begin by working with the $166.7_c$-$216.7_c$ M3 jins harmonic sika, retrieve the acceptable tunings of it, and tune the rest of the fundamental scale accordingly.

For the $166.7_c$-$216.7_c$ M3 jins harmonic sika, the tuning must be: E𝄳-($166.7_c$)-F-($216.7_c$)-G. If our starting E𝄳 is $350_c$ then F will be $350_c + 166.7_c = 516.7_c$. G will therefore be $516.7_c + 216.7_c = 733.3_c$. This gives us (E𝄳 $350_c$)-(F $516.7_c$)-(G $733.3_c$). This G is outside the perceptual range of G in the inherent fundamental scale. However, if we transpose the jins down one farab then we get ($350_c$ – $8.3_c$)-($516.7_c$ – $8.3_c$)-($733.3_c$ – $8.3_c$) = (E𝄳 $341.7_c$)-(F $508.3_c$)-(G $725_c$). Now, all three notes are within their perceptual ranges. If we transpose the jins down another step then we get (E𝄳 $333.3_c$)-(F $500_c$)-(G $716.7_c$); all notes are within their perceptual ranges, and G is closer to its median perceptual value of $700_c$. If we transpose the jins down another step then we get (E𝄳 $325_c$)-(F $491.7_c$)-(G $708.3_c$); G is now even closer to its value in the inherent fundamental scale, but E𝄳 has reached its lower perceptual boundary, which means we cannot transpose the jins down another step. To continue tuning the rest of the fundamental scale, let us choose the option where E𝄳 is closest to its value in the inherent fundamental scale, (E𝄳 $341.7_c$)-(F $508.3_c$)-(G $725_c$).

**7.4.3 Tuning the Rest of the Scale.** Now that E𝄳-F-G are tuned, the question is how to tune the rest of the scale. C must be $0_c$ and cannot be anything else otherwise we will have either tonic drift or a compromise in interval or jins identities; C = $0_c$ is the anchor to which the rest of the tuning pivots. D is the middle note of C-E𝄳. The question of tuning D is the same question of whether a N3 can be split into a M2 and a N2 to preserve the interval identities of the first two steps of the fundamental scale[1]. We know that it can because the N3 of 24 $_{EDO}$ does exactly that, splitting itself into a $200_c$ M2 and a $150_c$ N2. 144 $_{EDO}$ gives many combinatorial options for splitting a N3 into a M2 and N2. Let us simply pick a D that preserves the perceptual steps while making a

[1] C-D-E𝄳 can be thought of as jins sika reversed. We can tune it according to an outer m3, N3, or M3 while preserving the perceptual steps inside. Each choice, however, comes with its own consequences.

concordant 3rd with F. The default value of $200_c$ is a good option; it forms a $200_c$ M2 with C, a $141.7_c$ N2 with E𝄳, and a concordant $308.3_c$ m3 with F.

Next, we tune A and B𝄳. If we make A the P5 of D it becomes $900_c$, and if we make B𝄳 the P5 of E𝄳 it becomes $1041.7_c$. Both of these preserve the perceptual steps between G-A (M2 $175_c$), A-B𝄳 ($141.7_c$) and B𝄳-C ($158.3_c$). The $175_c$ step between G-A overlaps with the upper perceptual boundary of a N2, but historically N2s have always been intoned lower than that. Therefore, an interval of $175_c$ is malleable and can sound like both a N2 and a M2. The A also forms a $391.7_c$ M3 with F and a $300_c$ m3 with C; both are concordant 3rds. The B𝄳 forms a $316.7_c$ m3 with G and a $358.3_c$ N3 with D; the G-B𝄳 3rd is concordant, but B𝄳-D is not. Therefore, our maqam rast C scale becomes: (C $0_c$)-(D $200_c$)-(E𝄳 $341.7_c$)-(F $508.3_c$)-(G $725_c$)-(A $900_c$)-(B𝄳 $1041.7_c$).

***7.5 The New Harmonic Fundamental Scale***

The scale above has a N3 between degrees 1-3 and a M3 (in the form of jins harmonic major sika) between degrees 3-5. I have shown how a N3, m3, and M3 can all be split by a middle note to yield a M2 and N2 that are perceptually preserved. Let us see the different combinations yielded when these 3rds occupy degrees 1-3 and 3-5 and the different ranges of 5ths they produce between degrees 1-5 as a result, in the fundamental scale. Table 4 shows the possible combinations.

Two m3s together, as well as two M3s together, produce intervals that are outside the perceptual range of a 5th. They can thus be ruled out. We know that two N3s

**Table 4**

*Combinations of Thirds and the Sizes of Fifths they Produce.*

| | N3 | m3 | M3 |
|---|---|---|---|
| N3 | 650c-750c | 641.7c-691.7c | 708.3c-758.3c |
| m3 | 641.7c-691.7c | 633.4c | 700c |
| M3 | 708.3c-758.3c | 700c | 766.6c |

*Note*. The m3 and M3 are $316.7_c$ and $383.3_c$ respectively. They are the ones retrieved during development of jins harmonic sika and are the only concordant 3rds that are near the perceptual range of the N3: $350_c \pm 25_c$.

can be combined to yield a perceptually preserved 5th, like in $24_{EDO}$: $350_c + 350_c = 700_c$. Two perceptual N3s create a fifth with the perceptual width of a semitone. Given that two N3s are not concordant and do not aid in harmonization, the only reason to study their combinations would be to explain the different regional intonational profiles in the middle east and across different maqam cultures.

A m3 and a M3 combine to form the P5; degrees 2 and 4 can then be added to preserve all perceptual steps, but the fact that both N3s have been taken away might be too much information loss from the scale. Take for example the following tuning for the fundamental scale: $0_c$-$183.3_c$-$316.7_c$-$483.4_c$-$700_c$-$875_c$-$1016.7_c$. The identity of each perceptual step and each jins rast are preserved with the relative fundamental scale, but not the inherent. The melodic interval identity of all N3s in the scale has been compromised. Melodically, the scale produces a shockingly close intonation of rast. It might be very challenging to navigate the scale harmonically, however, as all the concordant 3rds might pull the ear towards western tonality, thereby compromising harmonic identity. The reverse version of this scale is to have the M3 on degrees 1-3 and the m3 on 3-5. It will produce a rast with a higher intonation of degree 3, and with the same features and potential issues.

A N3 and a m3 produce a range of fifths with a low perceptual range; some values are outside the range, while others come close to the inherent fundamental scale value of $700_c$. Similarly, a N3 and a M3 produce a range of fifths with a higher perceptual range; some values are outside the range, while others come close to $700_c$. These are the best combinations with the least compromises. When the N3 occupies 1-3, the m3 or M3 should occupy 3-5. Similarly, when either the m3 or M3 occupies 1-3, the N3 should occupy 3-5. This way, only one of the two N3s has been compromised, as opposed to both. The latter can be more troublesome because the characteristic degree of the fundamental scale is degree 3 and when it changes such that 1-3 becomes a m3 or M3 then the root jins identity can be compromised.

**7.5.1 The Perceptual Hierarchy of the Fundamental Scale**. From my analysis thus far in this paper, a perceptual hierarchy can be revealed for the fundamental scale, whereby compromises in higher positions cause larger perceptual informational loss to the overall perception of the scale:

1. Perceptual steps.
2. Perceptual thirds.
3. Larger perceptual intervals.

This is a hierarchical representation of maqam's pitch properties and applies to maqam music as a whole. Because maqam music is dominated by stepwise melodic development, preservation of the perceptual steps is most important to preserving the music's identity. Stepwise melodic development also entails skips (melodic movement by thirds) which can occur frequently, followed by steps in the opposite direction. However, they occur less frequently than steps, and thus they are lower in importance. Lastly, because maqam music does not have frequent movements by a fifth or more, larger perceptual intervals are the least important. If maqam music had frequent leaps, then the reverse would be true.

The perceptual hierarchy informs how to tune the fundamental scale so that it only loses the smallest amount of perceptual information possible. One possible procedure for doing so is:

1. Tune degrees 3-5 to jins harmonic sika.
2. Transpose jins harmonic sika up or down one farab such that degree 3 forms a central N3 ($333.3_c$-$366.7_c$) with degree 1.
3. Tune degree 7 to be a P5 of degree 3.
4. Tune 2 and 6 in a way that preserves the perceptual steps of 1-2, 2-3, 5-6, and 6-7 and creates concordant thirds between 2-4, 4-6, and 6-8. A P5 between 2-6 is possible.

***7.6 Perceptual Tempering Method: Analysis***

Because this tempering method considers research from studies on music perception, as well as the properties of maqam and harmony I have identified, which are themselves perceptual properties, I call it the perceptual tempering method. I will analyze the new fundamental scale in relation to the properties of maqam and harmony and point out new connections that are born out of the high connectivity that is offered by this tuning method.

**7.6.1 The Chord Progression Revisited.** The same chord progression was used with the following tuning for maqam C rast: $0_c$-$200_c$-$341.7_c$-$508.3_c$-$725_c$-$900_c$-$1041.7_c$. I will discuss a few noteworthy things. First, because this tempering method maximizes availability of 3rds, which compromises the 5ths, the $I^t$ chord can no longer be used because C-G is no longer a concordant fifth. The I chord will have to become octave doublings only. This is a permanent feature of the first degree of the fundamental scale, it does not accept non-neutral 3rds, because they compromise harmonic identity, and therefore it can only host a tonic chord that pairs octaves with an available fifth. In return, however, we have three complete triads: D-F-A, E𝄳-G-B𝄳, and F-A-C. F-C (691.7c) is not a P5, but it is more than acceptable, even in a non-forgiving piano timbre. G is also now a scale tone, requiring no comma variant for the 3 chord. Finally, one comma variant, Bb, was added so that the v and 7 chords can have concordant 3rds. Being beholden to the chord progression does not show the best qualities of this method, however; see the list of supplementary music examples for other works. An example of the chord progression in this method can be listened to on my YouTube channel[1] (Maqam Harmony, 2024f) (see the list of supplementary music examples).

[1] https://www.youtube.com/watch?v=-sKLW0FeN3w

**7.6.2 Harmonic Availability**. Recall that the concordance problem created a harmonic availability problem. Let us examine what lack of harmonic availability looks like in the wolf method compared with the perceptual tempering method. Tables 5 and 6 show whether a voice can move by a maximum of a 3rd to harmonize an incoming secondary field tone in another voice. Table 5 shows harmonic availability for the wolf method (just the 24 $_{EDO}$ notes) and table 6 for the perceptual tempering method. The constraint of a harmonizable option being a maximum of a 3rd away is important because anything higher than a third is considered a leap and will thus create perceptual segregation for that voice. This segregation is not conducive to the preservation of the

**Table 5**

*Harmonic Availability for Maqam Rast C in the Wolf Method.*

| | First note | Second note | Down | Oblique | Up |
|---|---|---|---|---|---|
| First Voice | F | E𝄳 | | | |
| Second Voice | C | ? | B𝄳 | None | E𝄳 |
| First Voice | F | E𝄳 | | | |
| Second Voice | D | ? | B𝄳 | None | E𝄳 |
| First Voice | F | E𝄳 | | | |
| Second Voice | E𝄳* | ? | None | E𝄳 | None |
| First Voice | F | E𝄳 | | | |
| Second Voice | F | ? | E𝄳 | None | None |
| First Voice | F | E𝄳 | | | |
| Second Voice | G | ? | E𝄳 | None | B𝄳 |
| First Voice | F | E𝄳 | | | |
| Second Voice | A | ? | None | None | B𝄳 |
| First Voice | F | E𝄳 | | | |
| Second Voice | B𝄳* | ? | None | B𝄳 | None |

* These are not sounded synchronously with the note above them, but rather as harmonic vertical non-chord tones.

property of stepwise melodic development. In the wolf method, the secondary field tones, E𝄳 and B𝄳, only have each other as harmonizable options, resulting in few accessible harmonizable options. In the perceptual tempering method, G can harmonize with the secondary field tones, giving a minimum of two options for every scenario. This occurs due to G filling the large gap of an open 5th between E𝄳 and B𝄳. Note that octaves and unisons are considered harmonizable options.

**Table 6**

*Harmonic Availability for Maqam Rast C: Ghammaz as Secondary Field Tone.*

| | First note | Second note | Down | Oblique | Up |
|---|---|---|---|---|---|
| First Voice | F | E𝄳 | | | |
| Second Voice | C | ? | B𝄳 | None | E𝄳 |
| First Voice | F | E𝄳 | | | |
| Second Voice | D | ? | B𝄳 | None | E𝄳 |
| First Voice | F | E𝄳 | | | |
| Second Voice | E𝄳* | ? | None | E𝄳 | G |
| First Voice | F | E𝄳 | | | |
| Second Voice | F | ? | E𝄳 | None | G |
| First Voice | F | E𝄳 | | | |
| Second Voice | G | ? | E𝄳 | G | B𝄳 |
| First Voice | F | E𝄳 | | | |
| Second Voice | A | ? | G | None | B𝄳 |
| First Voice | F | E𝄳 | | | |
| Second Voice | B𝄳* | ? | G | B𝄳 | None |

* These are not played synchronously with the note above, but rather as harmonic vertical non-chord tones.

This shows that creating the conditions for stepwise melodic development for any voice in a harmonic landscape depends on that voice's available harmonizable options; they must be no more than a third away from the previous note. Creating more concordant 3rds allows the scale to achieve this and ultimately leads to better stream coherence.

### 7.6.3 Stretching and Contraction: The Consequence of Prioritizing Thirds.

Maximizing available 3rds necessarily means to compromise the 5ths, resulting in a maqam meantone-like approach. Prioritizing small perceptual steps at the expense of larger perceptual intervals can sometimes lead to accumulated stretching or contraction. It can lead to some notes being far away from their theoretical values in the inherent fundamental scale. For example, when two $166.7_c$ N2 steps are placed in a row starting on D then we get: (D $216.7_c$)-(E𝄳 $383.3_c$)-(F $550_c$). D starts within its perceptual range, and even though each step is within the perceptual range of a N2, F ends up outside of its perceptual range in the inherent version of the scale. The perceptual steps, the smallest units of perception, can thus be more perceptually dominant than the absolute theoretical interval boundaries. When C ($0_c$) is played, however, F might be heard as too stretched. The two forms of perceptual boundaries, inherent and relative, must therefore conform to each other and converge to create an acceptable intonational profile. Contraction and stretching of intervals is a feature of some intonational profiles.

The perception of accumulated stretching and contraction can be explained through auditory scene analysis. Because the subsequent tone in a leap of a fifth is perceived as belonging to a different stream, the perception that the two tones belong to different sources is the default. That means that two tones a fifth apart do not need to be beholden to each other as they are already segregated perceptually. This means that the fifth could have a larger perceptual width than $\pm 25_c$.

Finally, it is better to have either uniform stretching (sharper) or uniform contraction (flatter) of the steps of the fundamental scale. Otherwise, some steps will be too large leading either to compromises in interval identity or stream segregation. Stretching takes the seventh degree closer to the tonic, reinforcing the leading tone relationship, whereas contraction flattens it away. This might be another reason why larger intervals are stretched, as discussed previously. Contraction, on the other hand, keeps degree 1-5 closer as one perceptual stream, which may be desirable as well.

**7.6.4 Maqam Harmonic Tonality: Samai Rast String Quartet.** The arguments behind the perceptual tempering method can be explored in my samai rast string quartet (Maqam Harmony, 2024i)[1] (see list of supplementary music examples). I composed the piece for rast C, but transposed it to C# to make it sonically different than the many available works in C. The tuning I used was: $0_c$-$216.7_c$-$358.3_c$-$525_c$-$741.7_c$-$916.7_c$-$1041.7_c$. Despite the fifth being ~$17_c$ sharper than its upper perceptual boundary of $725_c$, and ~$42_c$ sharper than its theoretical value, the musical work nonetheless sounds sufficiently like an Arab maqam rast. This is because the work preserves most, if not all, of the maqam and harmony properties I have identified, with the exception of some of the fifths, of course. There is simply much more room for theoretically informed intonational freedom than we have thought possible for maqam music.

***7.6.4.1 Horizontal Connectivity*.** Figure 4 shows the concepts I have discussed so far in this paper and the connections between them. I used the (0c-$200_c$-$341.7_c$-$508.3_c$-$725_c$-$900_c$-$1041.7_c$) tuning of the fundamental scale in the figure because it has

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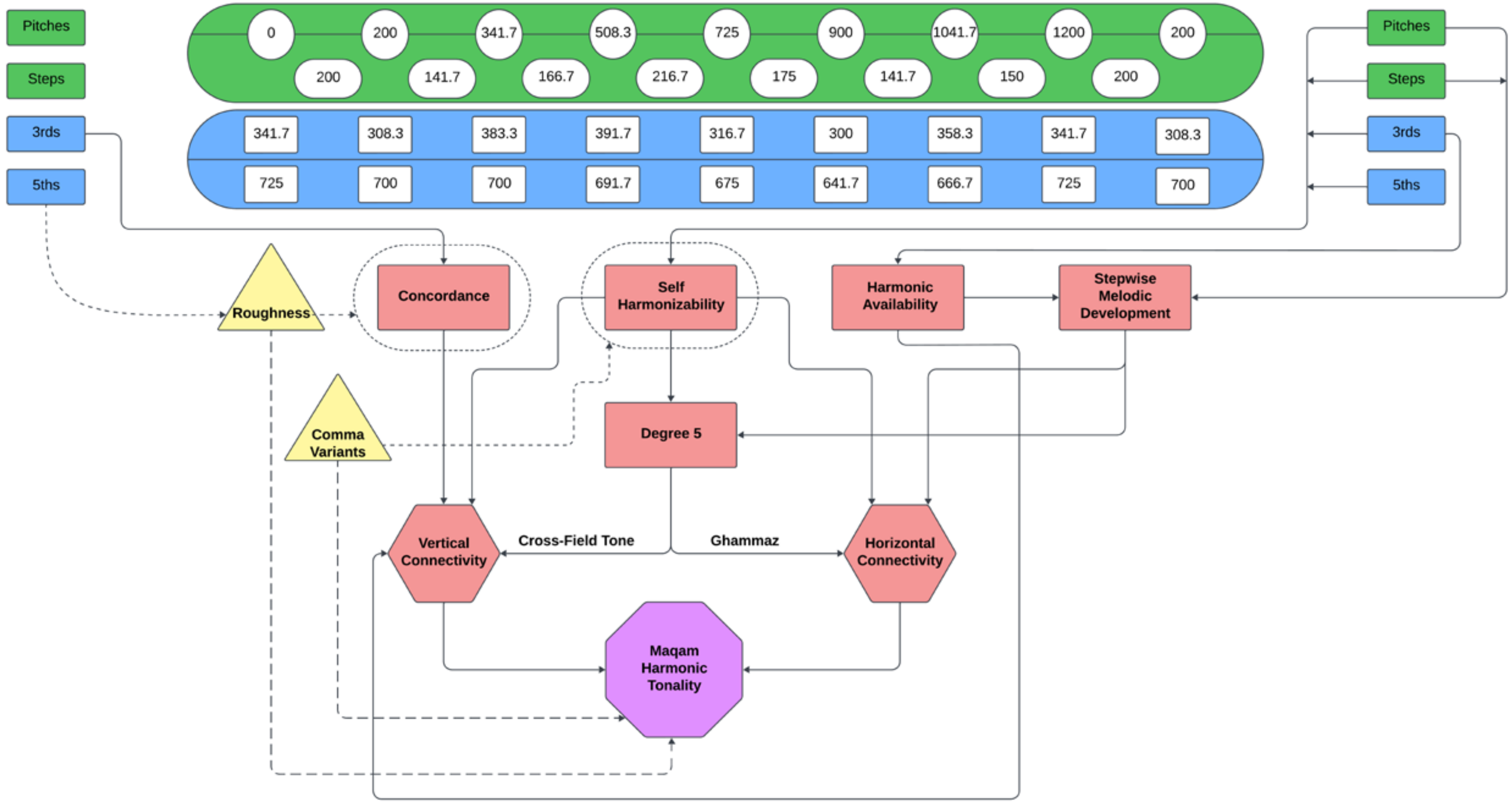
[1] https://youtu.be/01p0qweHdAo

the least amount of deviation from theoretical values. I will discuss the concepts and connections that have not been discussed yet. For example, stepwise melodic development in maqam music causes a tonal hierarchy to emerge. Of course, the tonic will be the most important tone that everything else is heard in relation to, but there are also other scale degrees that are frequented more often than others. The ghammaz is one such degree. It is usually frequented much more than the other degrees because it is part of melodic passages of both scale tones and chromatic sayr tones. Because it becomes the tonic of other ajnas and maqamat, it basically rarely changes throughout the work. This contrasts with other degrees that often get substituted so that the tones of other ajnas and maqamat can take their place. The ghammaz pitch can be part of a very large network of melodic modulations and sayr tones, just as it does in my samai rast string quartet. Together with the scale tones, and the ghammaz itself, the large network of the sayr tones creates high horizontal connectivity, which is an important contributor to the monophonic tonality aspect of maqam, and occurs irrespective of any harmony.

***7.6.4.2 Vertical Connectivity.*** Self-harmonizability is a property of a musical scale whereby the harmonic pitch material needed is within the scale and offers the concordance, or lack thereof, desired. It is one necessary condition for high vertical connectivity. When a scale tone has harmonizable options from both the primary field and secondary field, it becomes a cross-field tone. In my samai rast string quartet, the ghammaz is harmonized with all other scale tones of the fundamental scale.

**Figure 4**

*The Network of Maqam Harmonic Tonality for the Fundamental Scale.*



It is very befitting that the fifth degree of the fundamental scale, the ghammaz, becomes a cross-field tone because, as stated earlier, it is probably the most intoned pitch in a maqam musical work. When the ghammaz of the fundamental scale is able to create vertical connections with scale tones, as well as sayr tones, the result is high melodic and vertical connectivity. The high horizontal and vertical connectivity ultimately gives rise to the emergent phenomenon of harmonic tonality, the high integrated connectivity between a moderate number of nodes in a system. When both harmonic tonality and monophonic tonality combine, the result is a unique blend of maqam harmonic tonality; again, exemplified by my samai rast string quartet.

***7.6.4.3 Psychoacoustic Roughness Revisited.*** Both the $383.3_c$ M3 and $316.7_c$ m3 are mistuned, from 5/4 and 6/5 respectively, toward the neutral zone, as opposed to the minor or major zones; this allows these thirds to have better harmonic identity for the fundamental scale. The $383.3_c$ M3 is only slightly mistuned from 5/4 and the $316.7_c$ m3 is only one cent off from 6/5; thus, they are both very concordant. Mistuning direction is very important for the two reasons above; it allows very few m3s and M3s to substitute in place of N3s because they must be as near as possible to the neutral zone and as concordant as possible. $144_{EDO}$ is great for this.

In 24 EDO, it was difficult for us to use the N3s because of their high roughness. In perceptual tempering, the fifths can also be rough, and there is evidence that people have less tolerance for mistuned fifths than for thirds (Vos, 1982), but they can nonetheless be used because roughness decreases as the interval widens. In my samai rast string quartet, I used the ghammaz of 741.7c in synchronous vertical harmony with degree 1 (0c), and degree 2 (216.7c). These fifths are 741.7c and 675c , respectively.

You can hear it in the opening khaneh. Due to concordant thirds being used frequently, and strings being a forgiving timbre that can disguise mistuning, the result is a masking of the roughness. This psychoacoustic roughness is much more befitting of maqam music and can contribute to its harmonic tonality but must be used carefully.

***7.6.4.4 Comma Variants Revisited.*** If we want a system that maximizes the intonation accuracy of musicians, then we must limit the use of comma variants and seek a more self-harmonizable system. This way, musicians can deviate from it naturally to seek more concordance or expressiveness wherever they deem fit, but the fixed tuning of the scale will always be the anchor for them to return to. It is more effective to leave the adaptive tuning to the musicians, as opposed to notating it and expecting them to achieve it precisely.

Comma variants are not bad in and of themselves. We have already discussed how choirs and string quartets frequently play in adaptive tuning where all the pitches shift in a relational way to one another. However, what all these performers have in common is a tuning that acts as the anchor. They begin with it, deviate from it, and try to maintain convergence with it throughout the work. Similarly, the perceptual tempering method starts with self-harmonizability first, one fixed tuning for any scale. By creating enough harmonic availability, further options may not be needed. However, one or two comma variants can add the extra harmonic availability desired.

In my samai rast string quartet, I used the $1033.3_c$ comma variant of the $1058.3_c$ B𝄳 scale tone. It gave me access to a version of the v chord with a $291.7_c$ m3 between G and B𝄳 and a $383.3_c$ M3 between B𝄳 and D. It also gave me access to a vii chord with a

$383.3_c$ M3 between B𝄳 and D and a $308.3_c$ m3 between D and F. Also note that the $1033.3_c$ is still a B𝄳 of C.

**7.6.5 Arguments Against Compromising Fifths.** Some will argue that the relationship between degrees 1-5 must remain a P5 otherwise the intonation of maqam music will not be accurate. I invite those who believe so to listen to my perceptual tempering musical examples in the list of supplementary music examples to see that the perceptual information loss of maqamat is not necessarily large when fifths are compromised. Harmonically, we simply forgo harmonization via fifths if it is unbefitting of the musical work and use all the available thirds instead, which add more colorful character anyways. The idea that the fifth must be “perfect” is a relic of musical education and musical training that are themselves a result of mathematical ratio-based theories of music. When the medieval systematists, like al-Farabi, used mathematical ratios, it was simply the only means to carry out empirical analysis and documentation of the music of their day, the basis of which was divisions of a string. I am certain that some of them would completely abandon ratios and use empirical perceptual ranges in cents if they were conducting their work today. The 3/2 P5 ($702_c$) is indeed in the harmonic series, we just need to establish the boundaries that allow for good intonational approximations of it. Outside these boundaries, intonation error and mistuning are perceived. However, within the boundaries exist a wide range of intonational profiles, some of which are befitting of a harmonic system for maqam music that liberates concordant and non-rough thirds at the expense of perfection in fifths.

Some would argue that the ghammaz of the fundamental scale is a stable note, rather than a mobile one, and thus cannot accept such theoretical tuning deviations. I argue that the functionality of the ghammaz is preserved when its tuning is allowed to remain stable throughout the work. This is due to the property of sayr voice intonational profile consistency and is true for the function of any other degree. If the tuning of the scale degree conforms to the inherent and relative versions of its perceptual scale, and it is tuned consistently, then functionality is preserved.

The phrase: “if it looks like a duck, quacks like a duck, then it is a duck” should not apply haphazardly to the fundamental scale. The new fundamental scale may not look like the old rast from 24 $_{EDO}$. However, when compared with the perceptual fundamental scale, it does look like rast. Regardless, the fundamental scale does not need to look like rast, it simply needs to sound like one. The perceptual scale of 48 $_{EDO}$ should replace 24 $_{EDO}$ as the standard theoretical scale. Arab musicians have always known that there is a wide range of mobility for the secondary field tones. They now need to know that there is a wide range of mobility for the primary field tones; this includes fifths and any other interval.

### *7.7 Perceptual Tempering to Yield Other Harmonic Maqamat*

The tuning procedure I have identified for the fundamental scale can be utilized to yield other harmonic maqamat with preserved perceptual steps, maximized harmonic availability by maximizing available 3rds, and compromised fifths. Figures 5, 6, 7, 8, 9, and 10 show my tunings in 144 $_{EDO}$ for popular n-maqamat with the pink node as the tonic. The thirds and fifths that each scale degree forms with the scale degree twice and four times above it, respectively, are also given. The M3 jins harmonic sika should be used for maqam sika and maqam huzam (see fig. 5) because it is more reflective of their intonation[48]. I used the maqam huzam tuning in figure 5 to harmonize the song ạl̊war̊di gam̊ỹ̊l̊[49] by Umm Kulthum; the harmonization can be listened to on my YouTube channel[50] (Maqam Harmony, 2024g) (see list of supplementary music examples). However, a m3 on degrees 3-5 is reflective of the intonation of maqam musta'ar (see fig. 6); a good example to test this is raq̊ ạl̊ḥab̊ỹ̊b̊ by Umm Kulthum, minute 26:25[51]. Maqam bayati and maqam saba (see fig. 7) favor a contracted version of the root jins because the first step should be a smaller and softer N2 compared to that of rast.

One component of tempering is to select tones from the harmonic series as the scale tones; the advantage is that they can have a phase locking effect associated with concordance and consonance. The tones selected should also abide by the perceptual constraints and properties of maqam and harmony that I outlined. 144 $_{\text{EDO}}$ does a great job at meeting both of these conditions. For example, 383.3c approximates 5/4 and 291.7 approximates 13/11 (289.2c). Together, in a triad, they make the harmonic series segment 44:55:65 which, despite having the $675_{c}$ wolf fifth, can be both sufficiently stable and appropriate in terms of color for maqam music. Maqam Iraq (see fig. 8) is the seventh mode of maqam rast and should therefore be tuned the same way, but with a lower third degree that is more reflective of jins bayati. Maqam Bastanikar's (see fig. 8)

[48] This can be tested by trying both m3 and M3 versions of jins harmonic sika for songs in maqam sika or huzam.
[49] (Umm Kulthum - ام كلثوم, 2015b); https://youtu.be/LCra6PT_Ahk?si=cTK7ElfwvjISOU62
[50] https://www.youtube.com/watch?v=ttmxBudBsH4
[51] (Umm Kulthum - ام كلثوم, 2015a); https://youtu.be/DBDhNWwwsOc?si=2IHYHfZGL6K6diCp&t=1585

tuning loses the P5 between the secondary field tones but gains many thirds in exchange; very reflective of the popular song zalamouh by Abdel Halim Hafez[52]. Maqam sika baladi (see fig. 10) has the five quarter tones step and thereby confirms that it is indeed a step used in jins formation; the tuning yields many usable thirds.

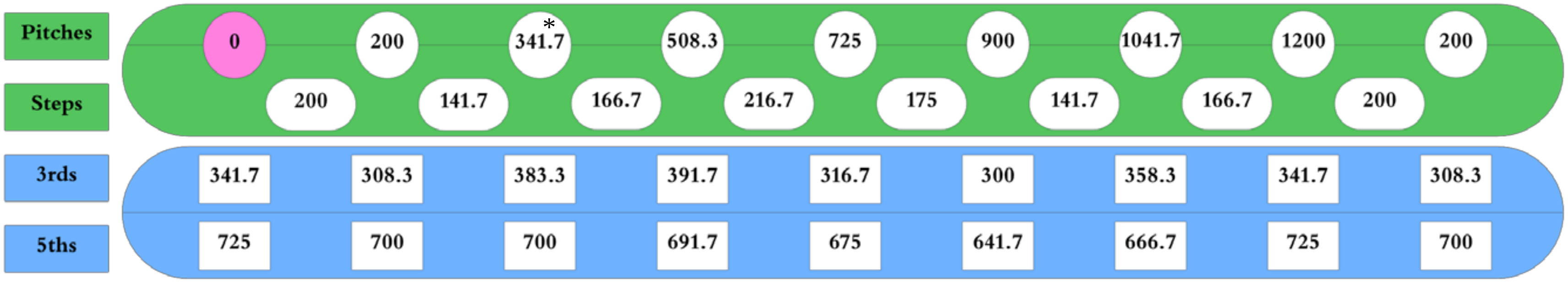
Maqam sazkar and maqam awj ara (see fig. 9) both have the theoretical quarter tone step. Touma (1996, p. 23) does not believe that this step exists in actual Maqam music. The quarter tone is not an interval with its own category because most scales across cultures do not use it. When it is surrounded by m2s, M2s, N2s, and augmented seconds, which dominate most music, the quarter tone will be perceived as a mistuned unison or semitone. Since we have to avoid the upper perceptual boundary of the unison (see fig. 11) due to limits in human JND perception, it is best to think of the quarter tone as the lower boundary of the semitone. In both maqamat, I tuned it to $66.7_c$ in 144 $_{EDO}$ which approximates Ibn Sina's 26/25 ($67.9_c$) quarter tone. Figure 11 summarizes the findings from the studies of Bharucha and Stoeckig (1986a), Brattico et al., (2006), Hunt (2008), Garza Villarreal et al. (2011), and Larrouy-Maestri (2018). It displays general perception of melodic tones, whether scale tones or comma variants, based on their distance in cents from the nearest scale tone (unison at $0_c$); the green and lighter colors will generally cause less perceptual issues.

[52] (Abdel Halim Hafez - عبد الحليم حافظ, 2015); https://youtu.be/RmlH2Es7-JY?si=7SyV34DiOiuB6DOG

**Figure 5**

*Maqam Rast, Maqam Sika, and Maqam Huzam With M3 Jins Harmonic Sika.*

## Maqam Rast and Maqam Sika




* Tonic of maqam sika.

## Maqam Huzam (Rahat al-Arwah)

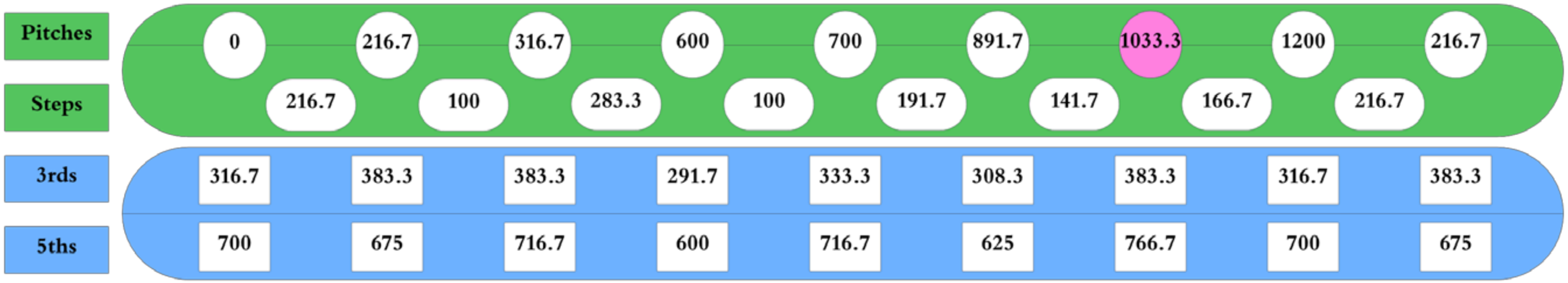


**Figure 6**

*Maqam Rast With m3 Jins Harmonic Sika, and Maqam Musta’ar With m3 Jins Harmonic Musta’ar.*

## Maqam Rast

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Pitches | 0 | 200 | 366.7 | 500 | 683.3 | 900 | 1066.7 | 1200 | 200 |
| Steps | | 200 | 166.7 | 133.3 | 183.3 | 216.7 | 166.7 | 133.3 | 200 |
| 3rds | 366.7 | 300 | 316.7 | 400 | 383.3 | 300 | 333.3 | 366.7 | 300 |
| 5ths | 683.3 | 700 | 700 | 700 | 716.7 | 666.7 | 633.3 | 683.3 | 700 |

## Maqam Musta’ar

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Pitches | 0 | 216.7 | 366.7 | 600 | 683.3 | 900 | 1000 | 1200 | 216.7 |
| Steps | | 216.7 | 150 | 233.3 | 83.3 | 216.7 | 100 | 200 | 216.7 |
| 3rds | 366.7 | 383.3 | 316.7 | 300 | 316.7 | 300 | 416.7 | 366.7 | 383.3 |
| 5ths | 683.3 | 683.3 | 633.3 | 600 | 733.3 | 666.7 | 800 | 683.3 | 683.3 |

**Figure 7**

*Maqam Bayati and Maqam Saba.*

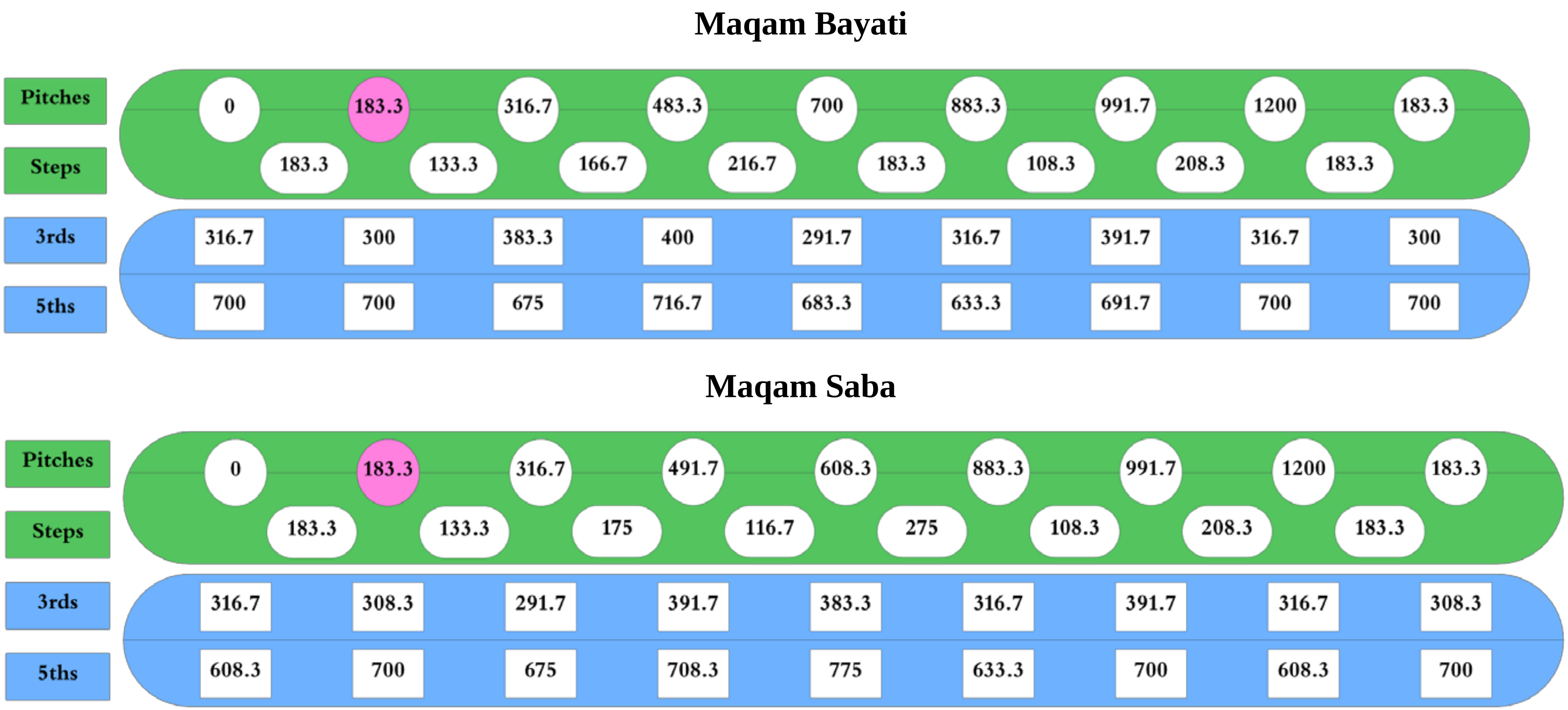


**Figure 8**

*Maqam Iraq and Maqam Bastanikar.*

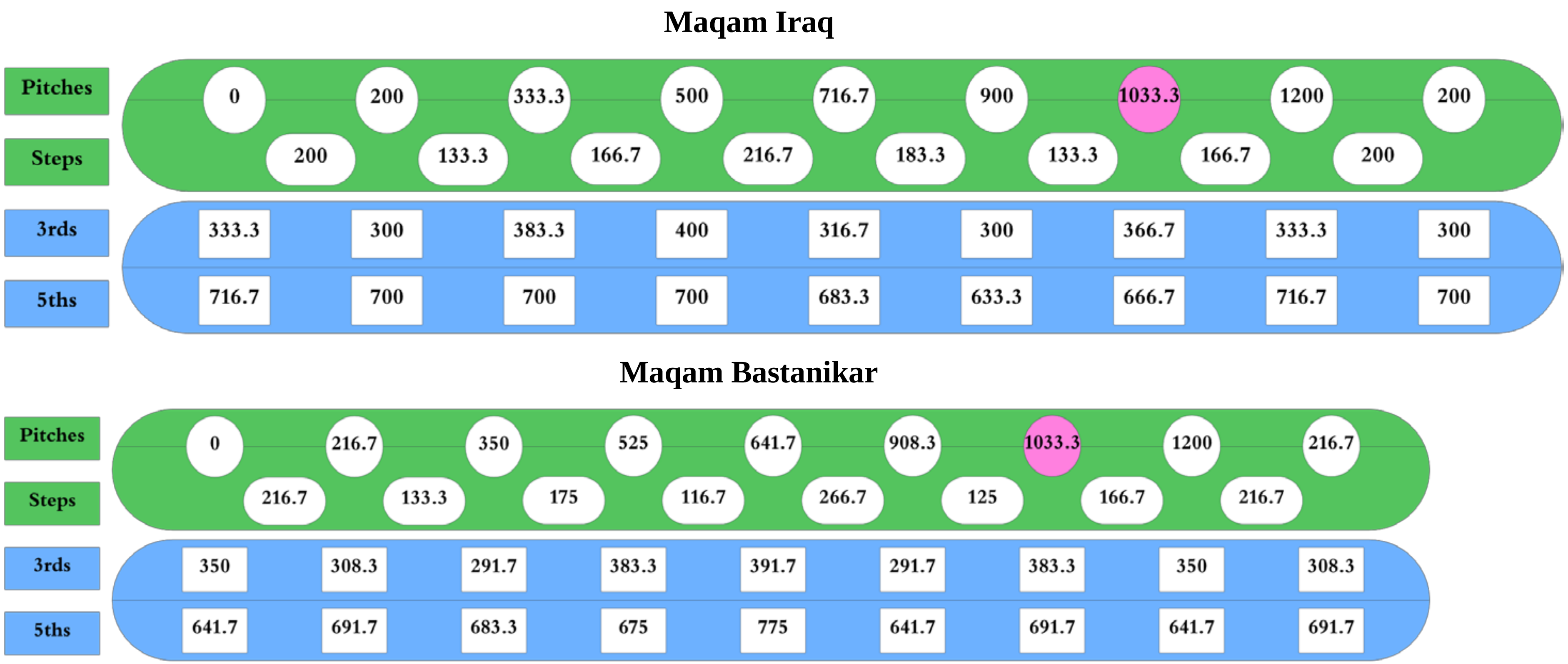


**Figure 9**

*Maqam Sazkar and Maqam Awj Ara.*

## Maqam Sazkar

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Pitches | 0 | 283.3 | 350 | 483.3 | 666.7 | 883.3 | 1050 | 1200 | 283.3 |
| Steps | 283.3 | 66.7 | 133.3 | 183.3 | 216.7 | 166.7 | 150 | 283.3 | |
| 3rds | 350 | 383.3* | 316.7 | 400 | 383.3 | 316.7 | 433.3 | 350 | 383.3 |
| 5ths | 666.7 | 600 | 700 | 716.7 | 816.7 | 666.7 | 633.3 | 666.7 | 700 |

* This third is formed with the fifth degree, $666.7_c$.

## Maqam Awj Ara

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Pitches | 0 | 283.3 | 350 | 600 | 666.7 | 983.3 | 1050 | 1200 | 283.3 |
| Steps | 283.3 | 66.7 | 250 | 66.7 | 316.7 | 66.7 | 150 | 283.3 | |
| 3rds | 350 | 316.7 | 316.7 | 383.3 | 383.3 | 216.7 | 433.3 | 350 | 316.7 |
| 5ths | 666.7 | 700 | 700 | 600 | 816.7 | 566.7 | 750 | 666.7 | 700 |

**Figure 10**

*Maqam Sika Baladi/Hijaz Ghareeb.*

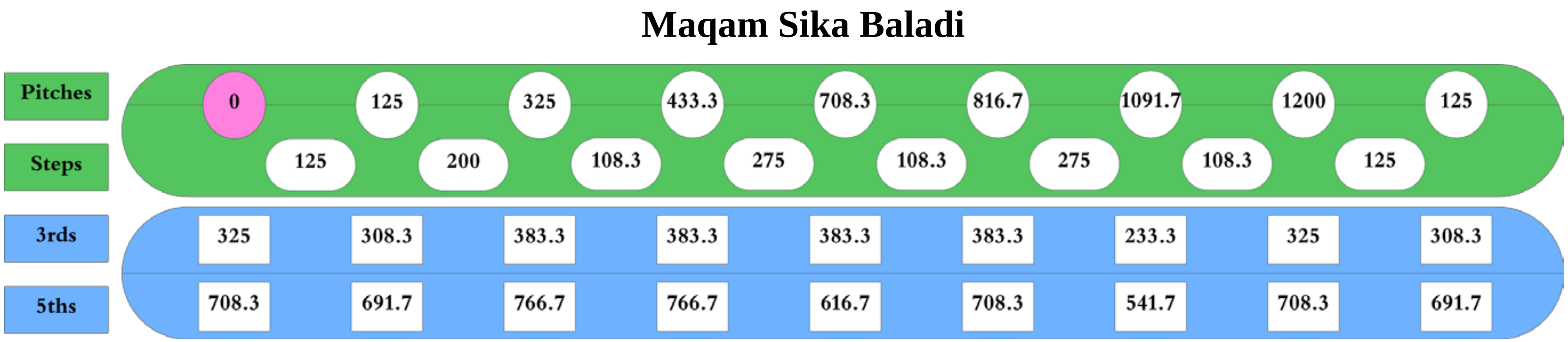
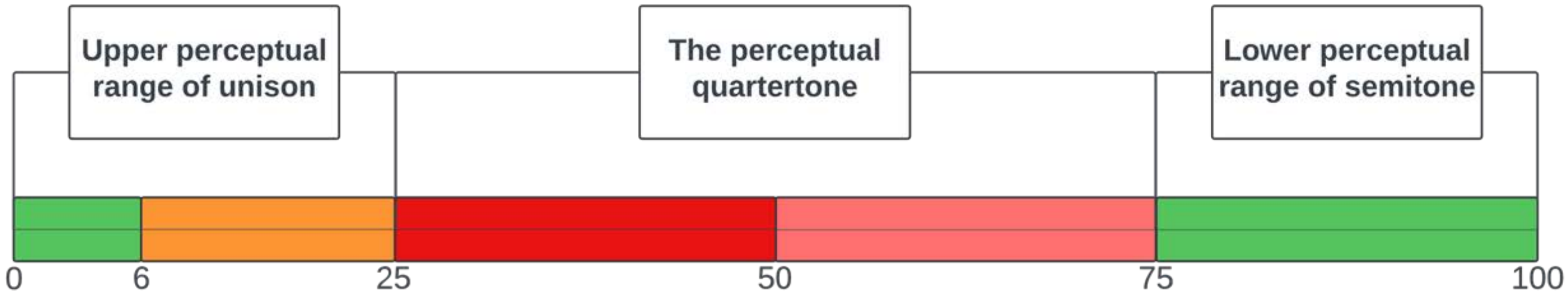



**Figure 11**

*Perception of Melodic Tones as a Function of Their Distance in Cents from the Nearest Scale Tone ($0_c$).*



## 8. Timbre Manipulation Methods

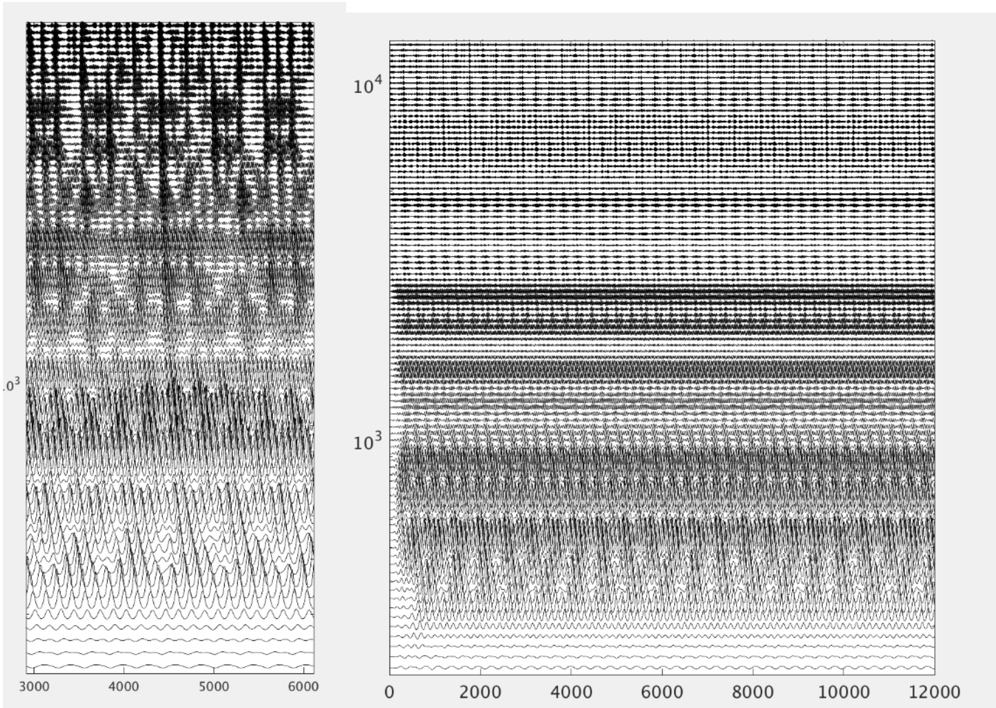
Aside from manipulation at the scale level, the timbre itself can also be manipulated to counteract the rapid amplitude modulation between partials that results in the perceptions of beating and roughness. This is done by manipulating the frequencies and amplitudes of the partials. One method is to move the partials themselves, by changing their frequencies, such that the final complex tone has overlapping partials and partials that are not near each other to cause roughness (Sethares, 2013). I call this method the partial frequency adjustment (PFA) method. However, the final spectrum will be inharmonic. *Harmonicity* is another element of harmony that is associated with musical consonance (Di Stefano et al., 2022). Maqam music's instruments produce harmonic or natural harmonic series – although any physical instrument can produce inharmonic partials – so an artificially made inharmonic timbre is bound to result in low harmonicity and likely low subjective consonance ratings. Certain bells, like the ones used in gamelan music, can be designed for maqam music, however. The inharmonic timbres in bells are perceptually smoother and more digestible. N3s are also much more digestible in bell-like timbres.

### *8.1 Partial Amplitude Adjustment (PAA)*

Fluctuation strength and roughness can be reduced the more the amplitude difference between the clashing partials approaches zero (Fastl & Zwicker, 2007, pp. 247-264). Therefore, we can ask the question: what is the least number of partials we can remove, by lowering their amplitudes down to zero, that will result in the least amount of fluctuation strength and roughness for the largest possible number of chords in maqam music? Figure 12 shows a visualization of the amplitude modulation between clashing partials of an 11/9 (~$347_c$) triad in root position on A 440hz. This is a gammatone filterbank that visualizes the amplitude modulation between all partials in a sound file (M. Battaglia, personal communication, January 21, 2021). Unlike roughness calculation models that only calculate sensory dissonance between a pair of partials

**Figure 12**

*Gammatone Filter Bank Visualization of Amplitude Modulation of Partials of an 11/9 N3 Triad.*




*Note.* The chord was generated using a computer synthesizer. The left panel has all the harmonics. The darker colors are a result of more amplitude modulation between interacting partials. The right panel shows the spectrum after the amplitudes of the multiples of harmonics 2, 5, 7, and 11 are all lowered down to zero.

or the sum of all pairwise sensory dissonance, this visualization shows where the clashing is happening and thereby indicates which harmonics to temper. We can then attempt solutions in an iterative way until the visualization shows reduced darker colors. When all multiples of 2 (2, 4, 6, 8, etc.), 5 (5, 10, 15, 20, etc.), 7 (7, 14, 21, 28, etc.), and 11 (11, 22, 33, 44, etc.) are removed as harmonics, the result is an 11/9 triad that is lesser rough and more digestible.

The above example uses a triad generated by a computer synthesizer with a sawtooth wave where every partial is mapped exactly as the harmonic of the fundamental. Commercially available synthesizers on the market use more complex synthesis methods, however. Pianoteq, for example, is a very flexible synthesizer that physically models the piano (*Pianoteq Overview*, n.d.). It uses an inharmonicity coefficient to simulate the stretched spectrum of real pianos. The same 11/9 triad recorded by Pianoteq and passed through the gammatone filterbank reveals that a new strategy is needed. When multiples of 3 and 5 are removed as harmonics in Pianoteq, the resulting spectrum allows for all kinds of neutral triads and notes to be played together in Pianoteq without the distraction of roughness that they can come with. This can be done in the pro version of Pianoteq by going to the note edit window, spectrum profile, and then lowering the amplitude of all multiples of 3 and 5 down to zero. This is exactly what I used in my harmonization of ʿinãạbī̊ which can be listened to on my YouTube channel (Maqam Harmony, 2024h)[53] (see list of supplementary music examples). All the instruments, apart from the piano, are tuned to a version of maqam rast based on my perceptual tempering method. The piano, however, aside from using

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[53] https://youtu.be/R5I0AgyeHy0

the same perceptual tempering tuning of the other instruments, it also uses the 3 & 5 PAA solution. The result is the best way to employ neutral chords, and they are extremely befitting of the genre of jazz music. I used all the neutral triads of the fundamental scale. The compromise of this method is the loss in *timbral fullness* (or richness) that comes from the removal of many partials of the spectrum. Table 7 lists all of the maqam and harmony properties I have outlined and the compositional and tuning methods that compromise them.

## 9. Practical Applications

All the compositional and tuning methods discussed can be utilized in digital music making. PAA can be used with many of the commercially available additive synthesizers that allow for amplitude adjustment of partials, like Serum (*Serum Advanced Wavetable Synthesizer*, n.d.). A combination of Pianoteq and keyboards should in fact substitute for real pianos in maqam music ensembles.

Given that comma variants can be difficult for musicians to achieve, I recommend the perceptual tempering method for music with real physical instruments. It allows for both homo-maqam and poly-maqam compositional techniques as well as polyphonic[54], homophonic, and monophonic textures. It can also be paired together with a few comma variants and the PAA method. This can be done by allowing the qanun to adopt the chosen temperament of the maqam, song, or concert, and letting all the other players converge their intonation to it. Of course, intonation variation will occur, but

[54] Listen to the fourth khaneh of my samai rast string quartet which has homo-maqam polyphony; https://youtu.be/01p0qweHdAo?si=Q76V4W5H2EousaK4&t=198

**Table 7**

*The Tuning and Compositional Features That Compromise the Properties of Maqam and Harmony Throughout Harmonization.*

| **Maqam's Pitch Properties** | **Tuning features** | **Compositional features** |
|---|---|---|
| Minimum step size of 50c | Comma variants | |
| Interval identity | Compromises in perceptual ranges | |
| Jins identity | Compromises in perceptual ranges | |
| Moderate number of scale tones | Comma variants | |
| Stepwise melodic development | Low harmonic availability | Leaping |
| Sayr voice intonational profile consistency | Deviations in tuning of melody | |
| Tonic stability | Tonic drift | |
| Acceptable usage of non-scale tones | Comma variants | Chromatic non-sayr tones |
| Monophonic tonality | | Tonicizing different tonics synchronously |
| **Harmony Properties** | | |
| Concordance of 8ves | Wolf 8ves | |
| Concordance of P5s | Wolf 5ths | |
| Concordance of 3rds | Wolf 3rds | |
| Harmonic identity | | Chromatic chord tones unbefitting of the maqam |
| Harmonic availability | Lack of available concordant 3rds | |
| Self-harmonizability | Comma variants | |
| Homophonic identity | Texture violations from comma shifts | Texture violations from unexpected chromaticism |
| Harmonicity | Partial frequency adjustment | |
| Timbral fullness | Partial removal | |

so long as all of the musicians converge their intonation with the qanun then the desired results of the temperament will be achieved. The old Arab qanun until the end of the 1970s had six pitches per string, giving flat, half-flat, natural, another natural, half sharp, and sharp (Pohlit, 2011, pp. 69-70). It has since been replaced with the 24 $_{\text{EDO}}$ qanun which, although allows for an acceptable intonational profile for maqamat, cannot give the intonational profiles of maqam harmony that allow for the preservation of both the properties of maqam pitch's and the properties of harmony.

Modern Turkish qanuns give access to the pitches of 72 $_{\text{EDO}}$ using all the mandals/'urab they come with (Pohlit, 2011; Pohlit, 2012; Yarman, 2008). Many Arab qanun players use these Turkish qanuns. The old Syrian qanun of Aleppo gave access to 13 pitches per string (whole tone), with flat being the first and sharp being the last (Pohlit, 2012, p. 70). The beloved songs and repertoire from Egypt's golden age of music during the 1950s to 1970s can be approximated really well with 72 $_{\text{EDO}}$. Therefore, the issue is not the feasibility of larger tunings on a qanun, but rather the will to abandon 24 $_{\text{EDO}}$ as a theoretical model and as a tuning for the Arab qanun.

I recommend 144 $_{\text{EDO}}$ as a tuning for the Arab qanun. Some tunings for harmonic maqamat only utilize pitches from 72 $_{\text{EDO}}$ so the aforementioned Turkish qanuns may be enough for a good amount of maqam harmony repertoire. For the ones that require 144 $_{\text{EDO}}$, however, some additional measures will be required. Applying 144 $_{\text{EDO}}$ practically can be as simple as using electronic tuners to tune some of the strings to give access to pitches from 144 $_{\text{EDO}}$. Another possibility is to have two 72 $_{\text{EDO}}$ Turkish qanuns side by side, tuned one farab apart, in an ensemble. Digital qanun and piano libraries can also be played by keyboard players. Alternatively, design and technological innovations to the 'urab and qanuns themselves can yield the desired qanun; many innovative ideas for the qanun are possible.

## 10. Conclusions

A one size fits all solution for music does not exist. The polyphonic compositional technique of poly-maqam allows for contrapuntal writing for maqam music but is not best suited to homophony. The tuning methods I have identified for homophony can each preserve some of maqam's pitch properties or properties of harmony while compromising others. My perceptual tempering method also compromises the concordance of fifths. However, because maqam music is dominated by stepwise melodic development, fifths are not hierarchically important for the music. The perceptual tempering method can also be combined with a few comma variants and the PAA method for a variety of digital and real music applications. The perceptual tempering method makes available many concordant thirds that promote stepwise melodic development. It allows for both homophony and polyphony to be used for all maqamat and thereby leads to the new emergent phenomenon of maqam harmonic tonality. If the perceptual tempering method is applied to the qanun then it can lead to the rise of maqam harmony for Arab ensembles.

Musical intonation is neither completely static, overlapping perfectly with theoretical values, nor completely dynamic, free from perceptions of mistuning and violations of expectations. My goal was to discover the perceptual range between theoretical in-tune-ness and out-of-tune intonation using studies from the literature on music perception. Within this range exist an array of many possible intonational profiles that preserve the melodic perceptual steps of maqam music and allow for concordant thirds that can be used for both polyphonic and homophonic textures.

The perceptual tempering method can be used in tandem with audio analysis methods to analyze regional intonational profiles in recordings. The aim would be to capture the intonational profiles, not via static cent values that do not reflect intonational variation, but by empirical perceptual ranges instead. This is a much more accurate way of documenting intonation and can help preserve a specific intonation as a cultural byproduct. With the help of music tuning experts, the method can then be used to construct and design harmonic and non-harmonic intonational profiles befitting of a particular maqam, song, project, film, city, country, or region.

**List of Supplementary Music Examples**

1. Maqam Harmony. (2024a, November 2). *Maqam Polyphony - Imitative Counterpoint Poly-Maqam for 4 voices* [Video]. YouTube. https://www.youtube.com/watch?v=eGgUnspuPd4
2. Maqam Harmony. (2024b, November 2). *Maqam Polyphony - Poly-Maqam Note Against Note Counterpoint for 3 voices* [Video]. YouTube. https://www.youtube.com/watch?v=IehItdUC43c
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